# GROWTH, FEED INTAKE AND DIET SELECTION IN PIGS : THEORY AND EXPERIMENTS

by

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*To my mother for everything*

*What has been will be again,*
*what has been done will be done again;*
*there is nothing new under the sun.*

ECCLESIASTES 1: 9

## ABSTRACT

A theory of growth and feed intake in the pig is proposed and the results of five experiments to test it are reported here. An attempt is first made to describe the potential growth in pigs, that is, growth under non-limiting conditions; the conditions needed to allow potential growth to be retained are then considered. Two ways of providing non-limiting feeding conditions are discussed: a single balanced feed and a set of feeds given as a choice. In addition, a model which predicts the voluntary feed intake of pigs is also developed and tested in experiments. The results from pigs offered single feeds in the first two experiments were consistent with the predictions of the model, which were that the rate of feed intake would increase as the protein content of the feeds was decreased. The size of the increase depended on the ability of the pig to lose heat. In these experiments, when pigs were offered a pair of feeds as a choice, a combination of which was non-limiting, the results suggested that this method cannot be successfully used to attain the potential growth of pigs. The diet selection results were characterised by a considerable variation in the diets selected by individual pigs, and only some pigs achieved what was estimated to be their potential rate of growth. It was suggested that pigs which failed to select a non-limiting diet did not have the necessary chance to choose. Experiment 3 evaluated a simple method of ensuring that pigs are given both the necessary choice, and the chance to choose. This was achieved by giving them the opportunity to sample the single feeds, which were to be offered as a choice, alone on alternate days for a short period of six days. Subsequently, pigs given a choice between two feeds were able to select a non-limiting diet. Experiment 4 incorporated the method established previously and consisted of a severe investigation into the rules of diet selection. It was concluded that pigs are able to avoid excess of nutrient, in this case protein, intake or to select the best possible diet in less favourable conditions, ie. a choice between two limiting feeds. The last experiment consisted of an extended test of the theory that a pig will select a diet which is a reflection of its degree of maturity, state and sex. Pigs made fat and delayed in growth in one period were subsequently given the opportunity to recover on a pair of feeds offered as a choice. The diets selected by the fat pigs satisfied their requirements for compensatory protein gain allowing only a slow rate of lipid gain. In addition, they met the different growth and fattening requirements by the two sexes. All these findings are discussed in relation to the use of choice-feeding as an independent test of other estimates of resource requirements, as a feeding technique when the potential growth of pigs is to be observed and as a help in predicting the feeding behaviour in pigs.

## DECLARATION

I declare that this thesis has been written by myself. The experimental work and analyses were carried out by myself, with the assistance of members of the Edinburgh School of Agriculture which is duly acknowledged. The results and the analyses have not previously been submitted for any other degree or qualifications..

Ilias Ioanni Kyriazakis

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# CHAPTER I

## THE PIG'S POTENTIAL FOR GROWTH

## 1.1 A DEFINITION OF GROWTH

There is some confusion concerning an adequate, or precise, definition of growth. Parks (1982) concluded that this was due to an understandable effort to define the growth of any organism in observable terms but broadly enough to include some factors which lie close to the causes of growth. In this thesis, the simplest definition, the one suggested by Aristotle, will be adopted: 'Growth is an increase in size'.

The view that an animal, given the opportunity, will progress towards a final size and form (which is the one of a fully reproductive individual), also derives from Aristotle's idea that:

> 'this is the most natural of the functions of such living creatures as are complete and not mutilated and do not have spontaneous generation, namely to make another thing like themselves, an animal an animal, a plant a plant'.

The final, mature size and the maximum rate at which an animal can progress towards maturity, when at a given size, are both taken to be determined by inheritance and coded in its genotype. The way in which an animal actually grows in an ideal or non-limiting environment is a reflection of this inherent potential for growth.

In this thesis, the term 'potential growth' will be used to describe 'measured growth under non-limiting conditions'. This definition presumes that ideal or non-limiting conditions can be found, and that the animal is able to make full use of them. A necessary corollary then is that the animal itself desires - or has a 'purpose' (Emmans and Fisher, 1986) - to achieve its potential and therefore to reach maturity in the shortest period of time.

## 1.2 THE MEASUREMENT OF GROWTH

The definition of growth implies that it is measured as an increase in size. The most familiar and obvious measurement of size is the weight of the body (Parks, 1982). However, while the liveweight measurement has the obvious advantage of being straightforward to make and repeatable on an individual, and for many purposes this is adequate, it is not a unique description of size (Armsby, 1917).

In 1859, Laws and Gilbert recognised that liveweight records alone were a poor way to measure growth, since differences may arise which cannot be defined as true progress to maturity (eg. the unpredictability of the weight of the gut contents). Later investigators (eg. Waters, 1908) suggested the linear measurements of the animal as the best repeatable measures of size. Some of these linear measurements (ie. girth diameter) share the same failings as liveweight in that they reflect primarily differences in gut-fill. Other measurements such as height at withers were found to be relatively good indicators of growth, showing growth of the skeleton, even when liveweight was static or decreasing.

Armsby and Moulton (1925) discussed the relationship between liveweight and, linear and chemical measures of size. They concluded that linear and anatomical measurements could not be always applied sensibly to matters of nutrition and it was the composition of the gain which best expressed growth. For Armsby and Moulton (1925) the body of the animal was considered as gut-fill and the empty body. The latter was defined as the sum of the weights of protein, ash, water and lipid, with the small amounts of carbohydrate being ignored.

Here, it is useful to see growth, firstly, as a gain by the body protein and ash, especially the former. The advantages of such a view were praised by Murray

(1922), since the composition of the non-fatty matter was not affected by conditions, but varied slightly with age (an idea which will be discussed later in detail).

Some authors have favoured the use of the change of body ash as the measurement of growth (Vohra, 1974; cited by Parks, 1982). However, since the lipid-free dry matter (the protein and the ash) is considered to be of constant composition, the increase in the lipid-free dry matter (hence called the remainder) weight in the animal will be regarded in this thesis, where possible, as contributing the most accurate measurement of growth. Though a reversible process under starvation, increase in remainder weight is considered to be the best indicator of progress towards maturity, because protein and ash are primarily structural components of the body and have direct relationship to the metabolic processes of the animal (Schmidt-Neilsen, 1984).

## 1.3 A DESCRIPTION OF GROWTH

Once growth has been defined and its method of measurement has been decided, the next step is to describe the maximum rate at which body size may be changed. The search for a universal growth function has been pursued by many biologists, who were mainly concerned with the prediction of liveweight gain of mammals and birds (Brody, 1945; Taylor, 1980c; Parks, 1982). However some of these functions can be also employed to predict the growth of a body component such as protein or remainder, as well as liveweight and it is the former use that will be stressed here.

The growth of an animal is taken to start at conception and finish at a mature equilibrium. The absolute growth rate needs to decline to zero as size increases to mature size. The growth equation will preferably have an economy of parameters, to which biological meanings could be attached and show properties of 'robustness

and simplicity of parameter estimation' (Taylor, 1980b). Such a list of specifications discourages the use of models which predict that growth takes the form of discontinuous phases, each of which requires its own set of parameters and estimating values. For example, Mitchell, Card and Hamilton (1931) described the growth of cockerels and pullets in the form of fourth degree polynomials, with each polynomial having five coefficients. Such fitted functions cannot represent the aetiology of animal growth, since their parameters cannot be interpreted in terms of the biology of the animal (Wilson, 1977). On the other hand, models that assume that growth can be described as simple convex or linear functions are also rejected since they suggest that either early growth (eg. embryonic) mirrors late growth, or that potential (protein) growth is constant over a wide range of its progress and independent of its state (Whittemore and Fawcett, 1976).

From the most commonly used equations (eg. Brody, 1945; von Bertalanffy 1957; Laird, 1966), there are two that seem to possess the properties required of a growth function. These are the logistic equation of Robertson (1923) and the Gompertz (1825) equation, adopted for biological phenomena by Wright (1926) and Courtis (1937). The two equations have some similarities. For example, they have the same numbers of constants (three), the degree of skewness is just as fixed in both, and the sum of many logistic or Gompertz curves approximates the logistic or Gompertz curve (Winsor, 1932). However, when Laird, Tyler and Burton (1965) compared the predicted specific growth rates of the two equations with actual data, they concluded that:

> 'the biological observation, that the empirically determined specific growth rate appears to decay proportionally with time, yields a specific model of growth, according to which the organism grows by fundamentally exponential process, which undergoes the observed decay over its whole range'.

This specific model was satisfactorily described by the Gompertzian growth equation but not by the logistic one (Laird *et al*, 1965).

According to this model, the relative growth rate of an empty body component of weight C, which is (dC/dt)/C or (dlnC/dt), is assumed to decline, linearly, as lnC increases and to be zero when $C = C_m$, where $C_m$ is the component weight at maturity.

Thus: $(dC/dt)/C = a - B_c \ln C$ kg/kg d (1)

When $C = C_m$, then $dC/dt = 0$, so $a = B_c \ln C_m$

by substituting (a) with ($B_c \ln C_m$) equation (1) becomes

$$(dC/dt)/C = B_c \ln C_m - B_c \ln C \quad \text{kg/kg d} \quad (2)$$

or $$dC/dt = C.B_c \ln (C_m/C) \quad \text{kg/d} \quad (3)$$

Substitution of $C/Cm = u_c$ (the degree of maturity of the component) into equation (3) leads to:

$$dC/dt = C_m.B_c.u_c.\ln (1/u_c) \quad \text{kg/d} \quad (3a)$$

Equation (3) expresses the growth rate of a component under non-limiting conditions in terms of its weight, C, and two animal characteristics, which are the rate parameter, $B_c$ and the mature size parameter, $C_m$. The maximum growth rate of the component occurs at 0.368 of the mature size and is ($B.C_m/e$) kg/d, where (e) is the natural number 2.718 (Figure 1.1).

Equation (3) can be integrated to give a Gompertz growth equation:

$$C = C_m.\exp (-\exp (-B_c (t-t^*_c))) \quad \text{kg} \quad (4)$$

where t equals time, in days, on some arbitrary scale and $t^*_c$ is a time constant, characteristic of the component.

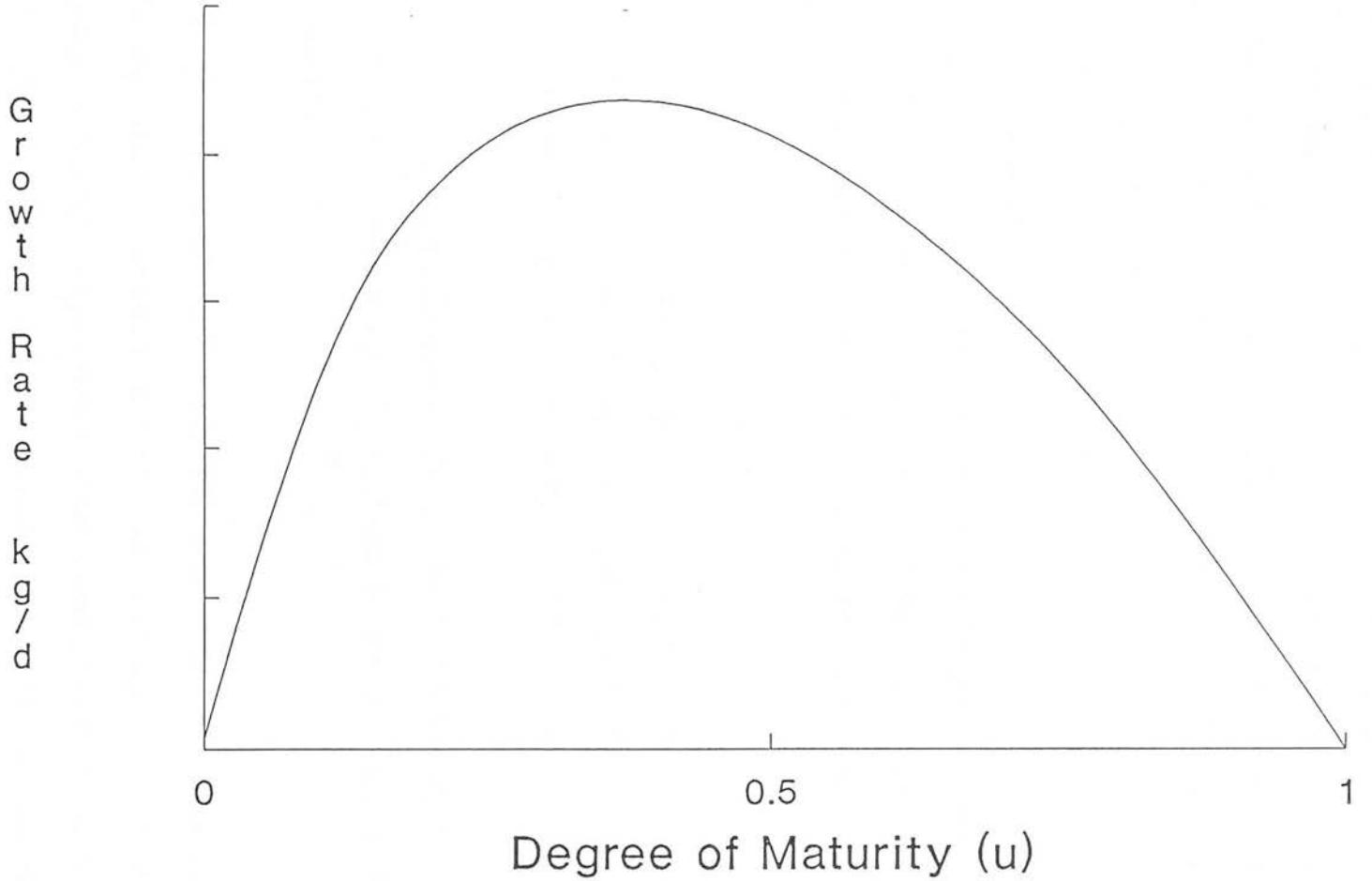


Figure 1.1 Growth rate of a body component in relation to degree of maturity of that component for a Gompertz growth function (equation 3a).

Equation (4) shows many of the properties required of a growth model: accuracy, simplicity and biological meaning. This equation was found to be a useful predictor of prenatal growth (Robinson and McDonald, 1979) and was favoured by Fisher (1980) and Emmans and Fisher (1986) to predict the rate of protein growth of chickens. Emmans (1984, 1985, 1986, 1987a, 1988a) has extended its use to pig, cattle, turkey and sheep data. Finally, Whittemore, Tullis and Emmans (1988) and Cropper (1987) have employed the Gompertz equation for the analysis of the growth of pigs and sheep respectively.

### 1.3.1 Simplifications of the Model

Equations (3) and (4) describe the growth rate of a body component under non-limiting conditions. As the empty body consists of the remainder (lipid-free dry matter), the water and the lipid, equation (4) can be rewritten for each body component:

| | | | |
|---|---|---|---|
| for the remainder | $R = R_m.\exp(-\exp(-B_r (t-t^*_r)))$ | kg | (5a) |
| for the water | $H = H_m.\exp(-\exp(-B_h (t-t^*_h)))$ | kg | (5b) |
| for the lipid | $L = L_m.\exp(-\exp(-B_l (t-t^*_l)))$ | kg | (5c) |

where $R_m$, $H_m$ and $L_m$ are the mature weights of each component, $B_r$, $B_h$ and $B_l$ are the three rate parameters and $t^*_r$, $t^*_h$ and $t^*_l$ are the three time constants for the three components.

Two assumptions are made. The first assumption, that the lipid-free dry matter is of constant composition, has already been made. Such an assumption suggests that the relationship between the two components of the remainder (protein and ash) is of the form $Y = a.X$ or $\ln Y = \ln a + \ln X$, which is described as isometry (Reeve and Huxley, 1945). The data of Doornenbal (1971,1975) presented in Figure 1.2 support the assumption made. The relationship between the natural logarithm of protein and the

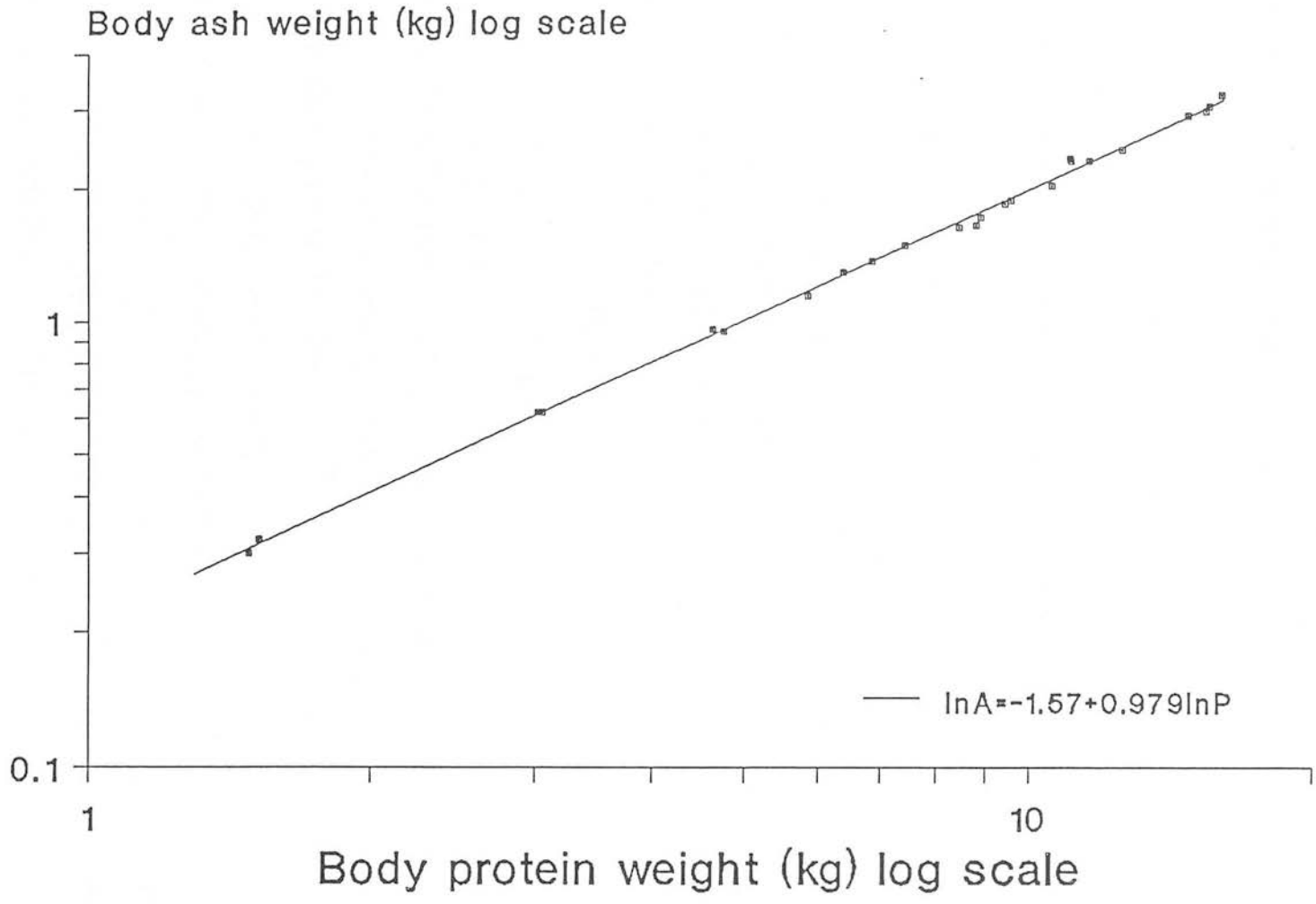


Figure 1.2 The allometric relationship between ash (A) and protein (P) in pigs ($A = 0.208P^{0.979}$). Data from Doornenbal (1971, 1975).

natural logarithm of ash, is of the isometric form, which gives a simple proportionality between the two components.

The second assumption is that the values of the growth rate parameters for each component are the same for a given genotype, so that:

$$B_r = B_h = B_l = B \qquad \text{per day.} \tag{6}$$

For each component, with $C/Cm = u_c$, equation (5) becomes:

$$u_c = \exp(-\exp(-B(t-t^*_c))) \tag{7}$$

so that:

$$u_r = \exp(-\exp(-B(t-t^*_r))) \tag{7a}$$

$$u_h = \exp(-\exp(-B(t-t^*_h))) \tag{7b}$$

$$u_l = \exp(-\exp(-B(t-t^*_l))) \tag{7c}$$

Taking the logarithms leads to:

$$\ln u_r = -\exp(-B(t-t^*_r)) \tag{8a}$$

$$\ln u_h = -\exp(-B(t-t^*_h)) \tag{8b}$$

$$\ln u_l = -\exp(-B(t-t^*_l)) \tag{8c}$$

dividing (8b) by (8a), after simplifying the exponents, gives:

$$\ln u_h/\ln u_r = \exp(B(t^*_r - t^*_h)) \tag{9a}$$

similarly dividing (8c) by (8a) gives:

$$\ln u_l/\ln u_r = \exp(B(t^*_r - t^*_l)) \tag{9b}$$

But B, $t^*_r$, $t^*_h$ and $t^*_l$ are constants, so we can write:

$$\exp(B(t^*_r - t^*_h)) = a \tag{10a}$$

$$\exp(B(t^*_r - t^*_l)) = b \tag{10b}$$

Combining equations (9) and (10) leads to:

$$\ln u_h = a.\ln u_r \tag{11a}$$

$$\ln u_l = b.\ln u_r \tag{11b}$$

from which follows that:

$$u_h = u_r^{\,a} \tag{12a}$$

$$u_l = u_r^{\,b} \tag{12b}$$

Thus, the degrees of maturity of water and lipid are predicted to be simple power functions of the degrees of maturity of the remainder.

But, by definition, $u_h = H/H_m$, $u_l = L/L_m$ and $u_r = R/R_m$

so:
$$H/H_m = (R/R_m)^a \tag{13a}$$

$$L/L_m = (R/R_m)^b \tag{13b}$$

Solving equations (13) for H and L, gives:

$$H = (H_m/R_m)\,(R_m^{\,1-a}).\;R^a \tag{14a}$$

$$L = (L_m/R_m)\,(L_m^{\,1-b}).\;R^b \tag{14b}$$

but $H_m$, $L_m$, $R_m$, a and b are constants , so we can write:

$$(H_m/R_m)\,(R_m^{\,1-a}) = c \tag{15a}$$

$$(L_m/R_m)\,(L_m^{\,1-b}) = d \tag{15b}$$

Combining equations (14) and (15) leads to:

$$H = c.R^a \tag{16a}$$

$$L = d.R^b \tag{16b}$$

which means that the water and lipid weights are related to the lipid-free dry matter weight by simple power functions.

Equation (16) is of the form of:

$$Y = a.X^b$$

which is the allometric equation used by Huxley (1932) to express the relationship between anatomical parts of the body. An allometric relationship exists for a given kind of animal when the graph of the natural logarithm of one part of the body against the natural logarithm of another part of the body is a straight line. Such a line has two parameters: the slope or growth coefficient (b) and the intercept (a), both of which are constant for a given part in a given genotype.

### 1.3.2 Tests of the model

The allometric relationship can also be applied to chemical data, to assess the relationship between the chemical composition of the empty body (Needham, 1932, 1934; Teissier, 1934; Emmans and Fisher, 1986). Two sources of data were used here, the only ones in the literature which cover an appreciable range of degrees of maturity of pigs fed under non-limiting conditions, to test the suitability of the model in summarising the changes in the body composition of pigs fed under non-limiting conditions.

The first set of data was that of Tullis (1981) on the chemical growth of Large White x Landrace pigs fed under non-limiting conditions. The growth of the three sexes (boars, gilts and castrated males) was measured from 52 to 322 days of age. The relationships derived from these data between the natural logarithms of the water and lipid and the natural logarithm of the remainder are shown in Figures 1.3 and 1.4 respectively. In both cases, for all three sexes, the relationships were linear and there was no pattern in the residuals. The two sets of equations show that there is little variability between sexes in the relationship of water to remainder, but the relationship between lipid and remainder varies between sexes (and possibly between breeds).

The second set of data was that of Doornenbal (1971. 1972, 1975) who measured the growth of castrated male Canadian Lacombe pigs from 44 to 211 days of age, when they were fed under non-limiting conditions. The estimate of the mature empty body weight ($EBW_m$) was 280 kg; the mature weights of the body components were calculated by iteration from the allometric equations.

The data have been analysed in accordance with a transformation of function (8), which by taking the logarithms becomes:

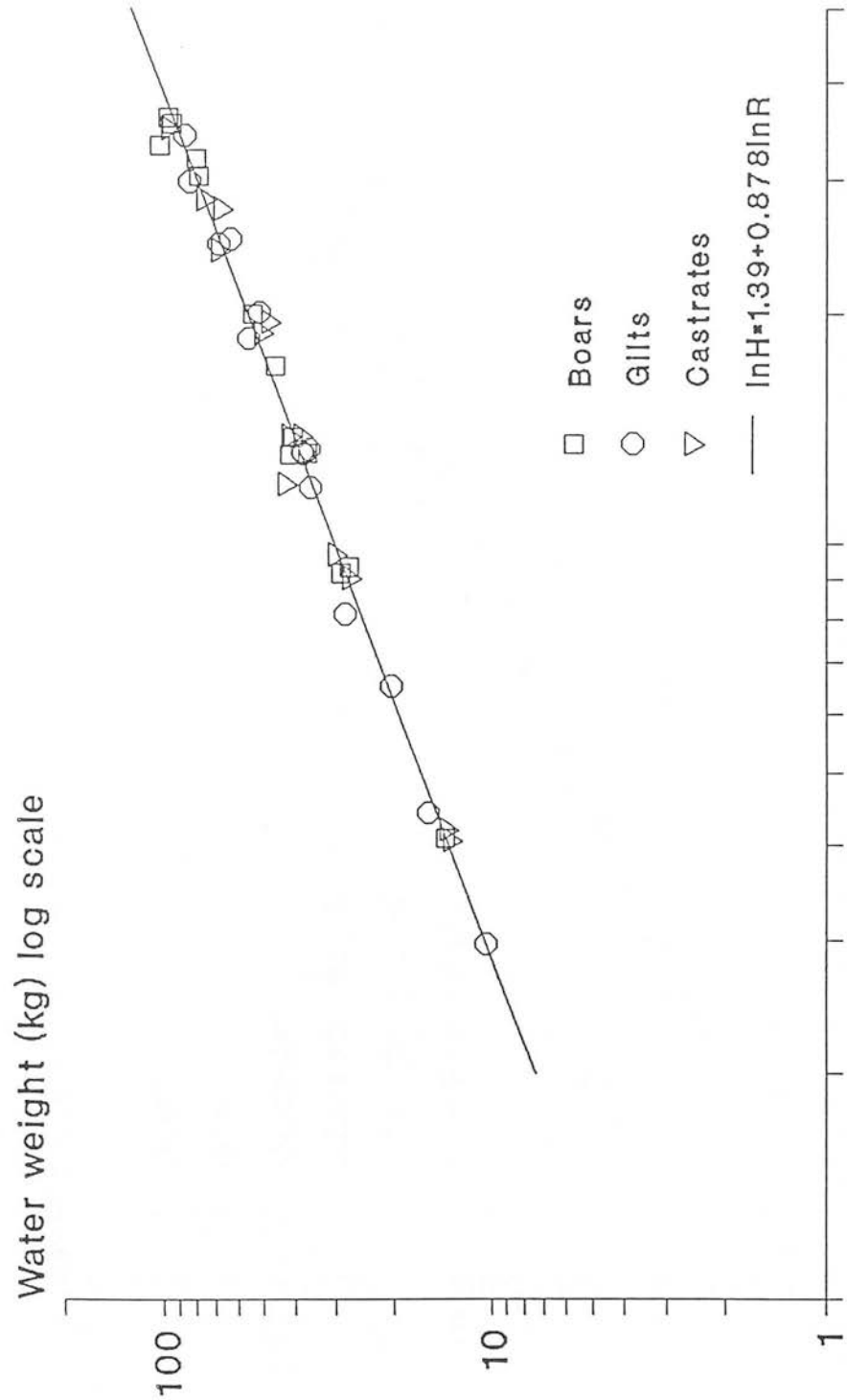


Figure 1.3 The allometric relationship between water (H) and remainder (R) in boars ($H = 3.82R^{0.898}$), gilts ($H = 4.22R^{0.858}$) and castrates ($H = 4.01R^{0.877}$). The solid line represents the relationship when the three sexes are considered together ($H = 4.01R^{0.878}$). Data from Tullis (1981).

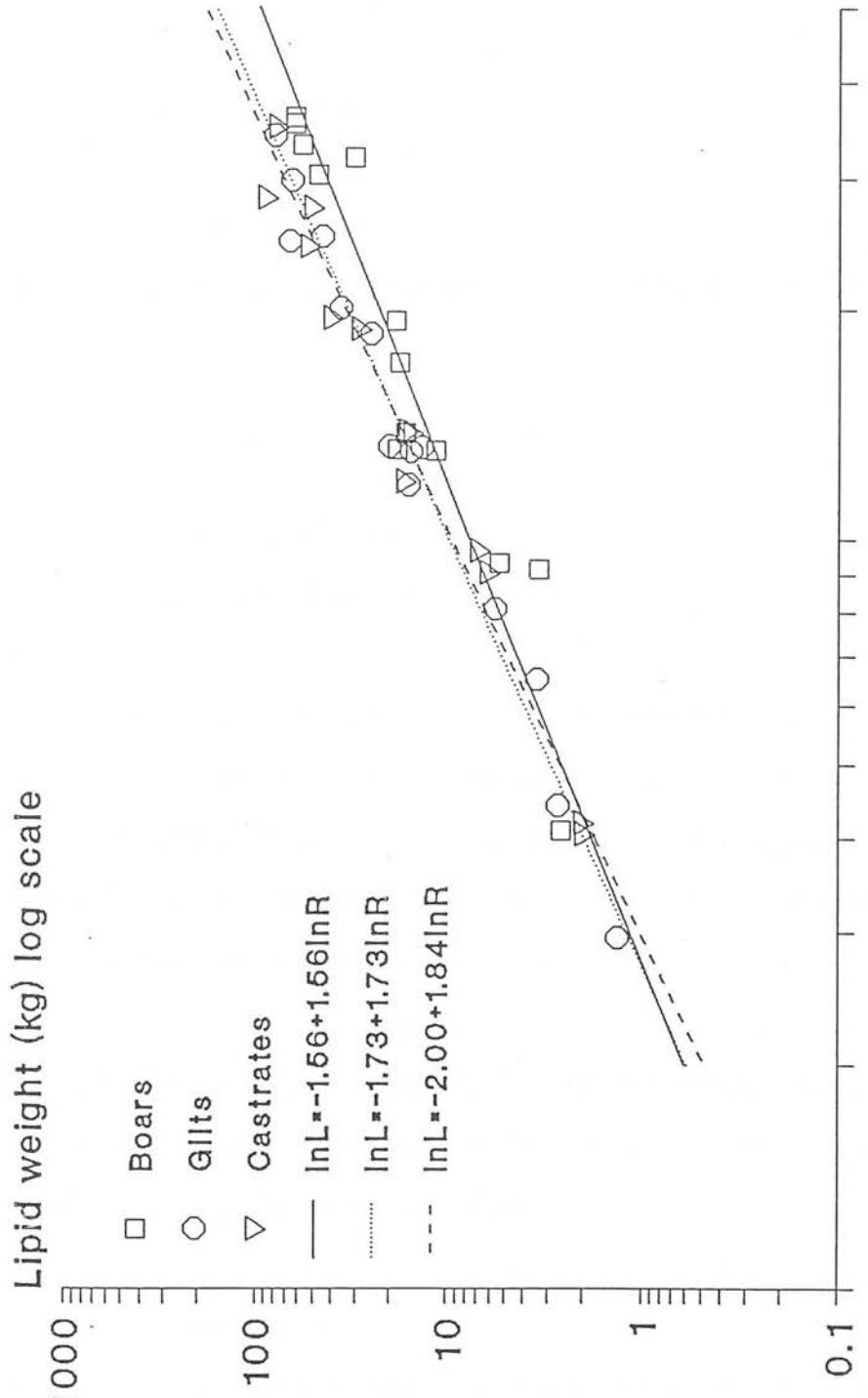


Figure 1.4 The allometric relationship between lipid (L) and remainder (R) in boars, gilts and castrates. Data from Tullis (1981).

$$-\ln(-\ln u_r) = (-B.t^*_r) + B.t \quad (22a)$$

$$-\ln(-\ln u_h) = (-B.t^*_h) + B.t \quad (22b)$$

$$-\ln(-\ln u_l) = (-B.t^*_l) + B.t \quad (22c)$$

by substituion of $G_c = -\ln(-\ln u_c)$, equation (22) leads to:

$$G_r = (-B.t^*_r) + B.t \quad (23a)$$

$$G_h = (-B.t^*_h) + B.t \quad (23b)$$

$$G_l = (-B.t^*_l) + B.t \quad (23c)$$

By using function (23) to analyse Doornenbal's (1971, 1972, 1975) data, the three equations derived were:

$$G_r = -1.50 + 0.00904\ t \quad (24a)$$

$$G_h = -1.38 + 0.00892\ t \quad (24b)$$

$$G_l = -2.01 + 0.00917\ t \quad (24c)$$

The correspondence between the form of the model and the data, which is illustrated in Figure 1.5 for each of the three components, shows that the model gave an adequate description of the actual growth of these pigs. The analysis of the data also justifies the assumption made previously that the values for the rate parameter ($B_c$) for each component are the same for a given genotype.

Therefore, the growth model survived the tests of two separate sets of data, and it was chosen as the most suitable candidate for analysis of the rate of a component gain of pigs fed under non-limiting conditions.

### 1.3.3 Relative Growth Rates

Given the growth rate of the remainder and the allometric relationship between both water and lipid and the remainder, the problem of describing the growth rate of an

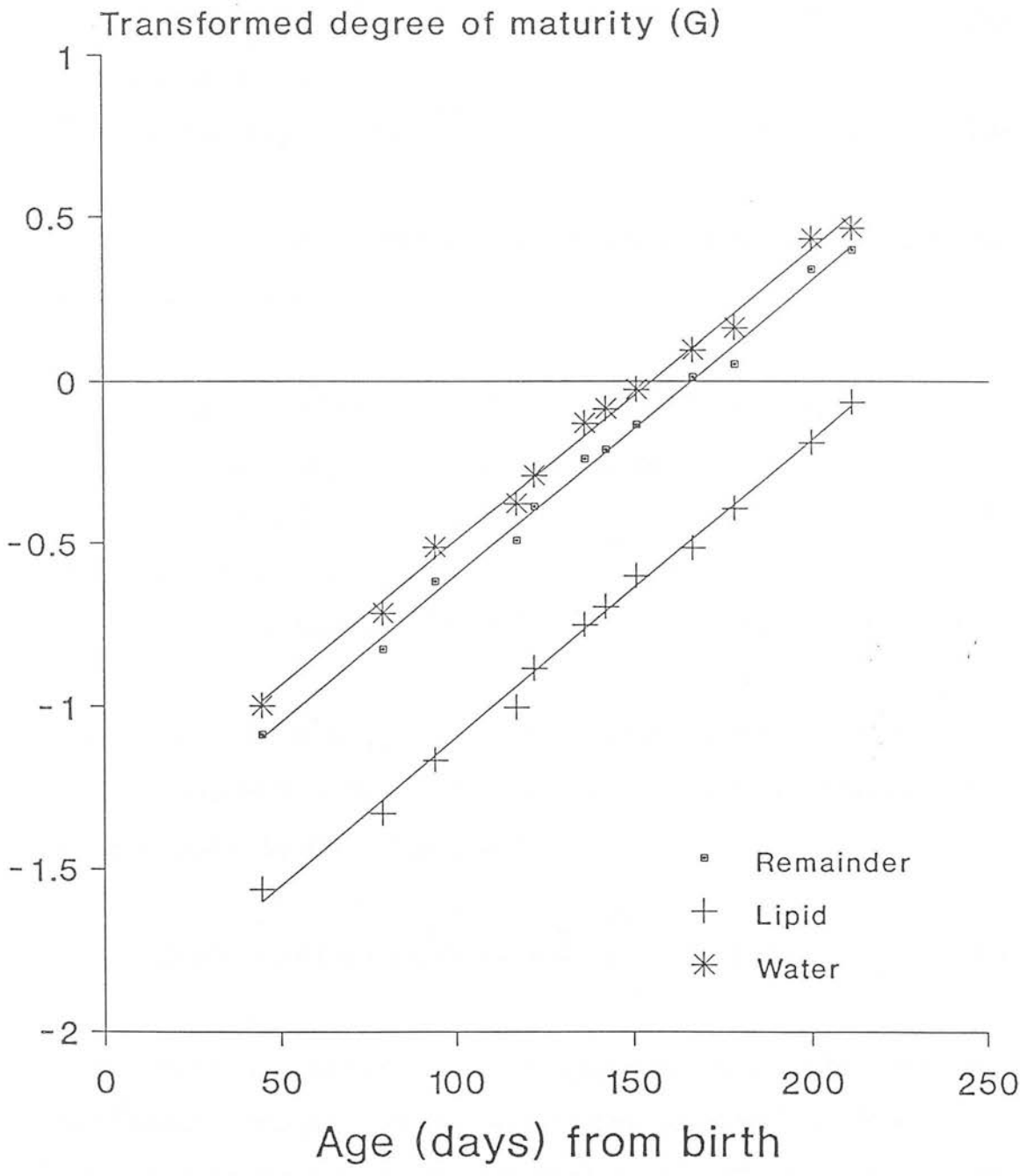


Figure 1.5 Transformed degress of maturity ($G_c$ = -ln (-ln $u_c$)) of components against time. The solid lines are given by the equations (24, a, b, c in the text). Data from Doornenbal (1971, 1972, 1975).

empty body component (dC/dt), can be changed into that of finding an equation which describes (dC/dR) since:

$$dC/dt = (dC/dR)\ (dR/dt) \qquad kg/d \qquad (16)$$

For water, equation (13a) is:

$$H = (H_m/R_m)\ (R_m{}^{1-a}).\ R^a \qquad kg \qquad (13a)$$

by differentiation we get:

$$dH/dR = (H_m/R_m)\ (R_m{}^{1-a}).a.R^{a-1} \qquad kg/kg \qquad (17)$$

Equation (17) can then be multiplied by equation (3) which describes the growth rate of the remainder, to get:

$$(dH/dR)\ (dR/dt) = (Hm/Rm)\ (Rm^{1-a}).a.R^{a-1}.R.B.\ln\ (Rm/R) \qquad kg/d \qquad (18)$$

substitution of $u_r = R/R_m$ into equation (18) leads to:

$$dH/dt = (H_m/R_m)\ R_m.u_r{}^a.a.B.\ln\ (1/u_r) \qquad kg/d \qquad (19a)$$

and similarly for the lipid:

$$dL/dt = (L_m/R_m)\ R_m.u_r{}^b.b.B.\ln\ (1/u_r) \qquad kg/d \qquad (19b)$$

The growth rate of the empty body (d EBW/dt) can now be seen as the sum of the growth rates of the three components (water, lipid and remainder). Consequently, by adding equations (3), (19a) and (19b) we get:

$$dEBW/dt = (dH/dt) + (dL/dt) + (dR/dt) \qquad kg/d \qquad (20)$$

Emmans and Fisher (1986) suggested that $H_m/R_m = 3.2$ and $a = 0.89$ can be assumed to be constant across genotypes and species, a view that is supported by the similar values of (a) appearing in the equations of Figure 1.3. The parameters then that describe potential growth are reduced to:

(i) $R_m$, a measure of mature size,

(ii) $L_m/R_m$ a measure of mature fatness,

(iii) B, the growth rate parameter, and,

(iv) b, the allometric parameter for lipid.

The model described here is able to give a reliable measurement of the growth rate of an animal fed under non-limiting conditions, after an estimation of $R_m$ has been made; a task that is more easily managed when the data set provides values of R close to maturity. It also provides measurements for the growth rate of lipid under non-limiting conditions, when an estimation of $L_m$ is given. This lipid growth rate for the purposes of this thesis will be described as desired lipid gain or desired lipid:protein ratio (fatness), when conditions for the fulfilment of the potential are considered. However, whereas the growth rate of the remainder under non-limiting conditions represents the potential rate at which an animal can grow, the desired lipid growth rate is considerably smaller than its maximum lipid growth rate, which can be manifested under some feeding conditions (Chapter II).

### 1.3.4 The Liveweight Gain

It would be useful if the growth of the various body components could be brought together to describe the gain in liveweight, in a similar way as in equation (20) which described the gain of the empty body weight. Such a description would describe the progress of the whole animal in a way which is readily measurable and repeatable.

As discussed previously, there is no simple description of liveweight growth mainly due to the unpredictability of the gut-fill, whose composition is not a constant either across time or treatments (Fisher, 1983). Both gut-fill and the gut itself fail to exhibit an allometric relationship with the empty body, or indeed with any body component (Hammond, 1932). Suggestions for the prediction of gut-fill have been made by Emmans and Fisher (1986) and Kirkwood and Prescott (1984). The former suggested that gut-fill could be predicted from the knowledge of the rate of feed

intake and the composition of the feed. The latter adopted a similar approach, by attempting to relate the gut-size to both degrees of maturity and the rate of feed intake.

However, by aggregation of the Gompertz curves of allometrically related components, the Gompertz equation can often give as good a description of liveweight gain as Brody's curves (Taylor, 1968; Tullis, 1981) or other liveweight functions (for example, that of Parks, 1982). Consequently, the equation used to describe the changes in liveweight is of the form of the equation (4):

$$W_t = W_m \exp(-\exp(-B_w (t - t^*_w))) \qquad \text{kg} \qquad (21)$$

where $W_t$ is an immature liveweight at time t (in days), $W_m$ is the mature liveweight, $B_w$ (per day) is the rate of attainment of maturity and $t^*_w$ the time constant, characteristic of liveweight. In this case, $B_w$ will have a value different to that of $B_c$ for each component (Winsor, 1932).

By taking the logarithms and substituting $W_t/W_m = u_w$, equation (21) becomes:

$$-\ln(-\ln u_w) = (-B_w t^*_w) + B_w t \qquad \text{kg} \qquad (22)$$

Equation (26) can then be used to estimate $B_w$ since:

$$-\ln(-\ln u_{w2}) + \ln(-\ln u_{w1}) = B_w (t_2 - t_1) \qquad \text{kg} \qquad (23)$$

where $u_{w1}$ and $u_{w2}$ are two different degrees of maturity and $(t_2 - t_1)$ the time taken to reach from $u_{w1}$ to $u_{w2}$.

Gompertz functions, in the form of equation (23), have therefore been used to analyse the liveweight data of Stamataris, Hillyer, Whittemore, Emmans, Taylor and Phillips (1985) who grew Cotswold Large White x Landrace pigs under non-limiting conditions[1]. The estimate of the mature liveweight ($W_m$), derived from another experiment with Cotswold Large White x Landrace pigs (Young, Phillips, Whittemore and Eastham, 1988), was 300 kg. The mature liveweight of boars was estimated to be the 1.17 $W_m$ of the sow (350 kg). The $B_w$ value of Cotswold Large White x Landrace pigs was then calculated to be 0.0138 (s.e. 0.0003) per day and 0.0141 (s.e. 0.0003) per day for the sows and boars respectively. These two descriptions ($B_w$ values) are used in the following experiments as the best estimates of judging the liveweight performance of test Cotswold Large White x Landrace pigs.

## 1.4 STANDARDISING POTENTIAL GROWTH

There is widespread evidence that there is a similarity in the growth processes of different genotypes and it derives from many genetic relationships now established for differences between species, breeds, sexes and individuals (Brody, 1945; Taylor, 1965, 1968; Kirwood and Webster, 1984; Kirwood and Prescott, 1984). Brody (1945) suggested that 'a fundamental characteristic of living things is that they are alike in general plan and differ in detail'. His work on a wide range of mammalian species clearly showed that the times that different animals take to pass between two degrees of maturity is related to mature size (ie. species with larger mature size, take a longer time to mature), but it was left largely undeveloped.

Taylor (1980a) offered the most complete proposals of genetic scaling rules for standardising mammalian growth curves, with respect to the genetic difference in body size. The two rules reported in his paper are:

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1 *The description of non-limiting conditions and the justification for using this data will be given in Chapter II*

1. Treat all age and time variables for the $i^{th}$ genotype as directly proportional to $A_i^{0.27}$, where $A_i$ is the mature body weight of the $i^{th}$ genotype.
2. At every age standardised treat all cumulative inputs and outputs for the $i^{th}$ genotype as directly proportional to $A_i$.

Taylor's first rule implies that the scaling is such that the time taken to mature, when divided by $A^{0.27}$, is uncorrelated with A across species. This suggests that the method of Taylor (1980a) can be used to formulate the general proposition that there are no differences in the potential growth of different breeds once their growth curves have been standardised by application of the scaling rules. In other words, that across genotypes the growth rate parameter (B) could be related to $R_m$, such that a scaled rate parameter ($B^* = B.R_m^{0.27}$) would be uncorrelated with $R_m$; that is to say that $B^*$ can not vary across genotypes.

This proposition was proved to hold when Taylor (1965, 1968, 1980a) reanalysed the large and diverse set of Brody's (1945) data on the mature body weight of mammalian species. However, these domesticated species were subjected to a rather lesser degree of genetic selection and nutritional largesse than that of modern meat animals. The proposition was also true for comparisons between the breeds of a species which have evolved more or less naturally, such as the different sheep breeds. McClelland, Bonaiti and Taylor (1976) made standardised comparison of four sheep breeds grown under non-limiting conditions. Breed and sex differences were reported to have disappeared at the same degree of maturity when the data were expressed as percentage proportions of body or carcass weight.

However, this proposition could not hold for comparison between breeds or species selected for meat production. Wilson (1977) reported that modern broiler chickens have a higher value of $B^*$ value than either old meat stocks or modern laying strains.

Webster, Ahmed and Frappell (1982) found differences in maturation rates mainly between the bulls of the Hereford breed (or other breeds selected for beef production), who matured faster than the Friesian dairy bulls.

The two examples used in this thesis (ie. the Lacombe pigs (Doornenbal, 1971, 1972, 1975) and the Landrace x Large White (Tullis, 1981)) substantiate the latter suggestion. The two breeds -which represent an unimproved and a modern genotype respectively - have different growth rate parameters and enormous differences in body composition (the Lacombe being more than twice as fat at maturity). However, since both breeds have a very similar mature weight, the application of Taylor's rule cannot account for these differences.

Most modern meat stocks have been subjected to an intensive selection towards faster growth and correlated increases in the mature body size (Fowler, Bichard and Pease, 1976). They have also been selected for a reduced fatness, which may or may not have changed the $L_m$, but has certainly affected the lipid:remainder ratio at maturity (Emmans, 1987b). Therefore, when we are dealing with comparisons between breeds it is useful to have a measurement of $R_m$ at maturity. Whittemore and Tullis (1987) have stressed that such measurements are prerequisite to the provision of a quantitative description of improved pig genotypes.

It is also important before drawing conclusions to subject pig breeds to considered and systematic comparisons, employing standardising techniques for analysis of the growth data of pigs reared under non-limiting conditions. When comparisons are made under conditions where the nutrition of the pigs was subject to some constraints they are not always valid since limiting conditions can affect significantly the fattening characteristics of pigs (as it will be discussed in the following chapter).

# CHAPTER II

## NON-LIMITING CONDITIONS FOR THE GROWTH OF PIGS

*Brussels*

## 2.1 INTRODUCTION

The idea introduced in Chapter I was that an animal inherits a growth plan which determines, for that individual, the upper limit to its growth rate towards a final mature size. This upper limit represents the potential rate of growth of an animal, that becomes actual when the increase in size accords with that of the inherited growth plan.

Aristotle's further observations on animals suggested that they also possess the desire to progress towards a final size, since:

> 'all creatures desire this [to progress towards a final mature size] and for the sake of this do whatever they do in accordance with their nature'

Therefore, for Aristotle an animal inherits not only its growth plan, but also the motivation and the means to attain its potential growth rate, given, presumably, the opportunity.

## 2.2 THE CONCEPT OF THE REQUIREMENTS

The above suggestion implies that an animal has certain resource requirements to satisfy its growth plan and to maintain its current state. These resources can be obtained by the animal only through its feed[2], and therefore an animal is assumed to seek to eat because it seeks, or it is motivated, to grow at its potential. The problem is then to be able to calculate the requirements of animals in terms that can be made consistent with the description of feeds (Emmans and Oldham, 1988).

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2 *The requirements for water, though very important, will not be considered in this thesis.*

Armsby (1917) suggested that both the feed and the animal can be related to one another in terms of matter and energy. The material composition of the feed can be regarded as water and dry matter. The dry matter in turn consists of organic (ie. protein, lipid and carbohydrates) and inorganic matter (ash). Here, the dry matter of the feed will be regarded as yielding three components to the animal: protein, energy and ash.

The growth plan of a pig has already been described in chemical terms in Chapter I, as the potential rate of gain of the lipid-free dry matter or remainder, together with a desired rate of lipid gain, associated with strict ratios of water and lipid to the remainder. This stored, or retained, matter can be expressed at the same time as a store of potential energy. Instead of using lipid-free and lipid weights it is more convenient to use total protein and lipid weights for calculating requirements. This is because the protein content of the lipid-free matter increases systematically with progress towards maturity. It is not necessary to consider ash separately from protein as the ash:protein ratio does not change with degree of maturity (Chapter I). Therefore, such a correspondence between the animal and the feed in chemical descriptions, permitted Waters (1908) to suggest that an animal has resource requirements for the following:

(a) Maintenance

(b) Production of growth (protein + water + ash)

(c) Production of fat

Waters (1908) suggested that the full and complete requirements for maintenance, which is the rate of zero state change, must be satisfied before any growth can occur. Feed ingested in excess of maintenance will take the form of growth, up to the maximum which is determined by the genotype and state. Any feed ingested above the needs for maintenance and growth will be stored in the body as fat.

This paradigm identifies a problem: what are the maintenance requirements for energy, protein and ash and on what scales are these requirements measured? Maintenance can be defined at some level of activity in a thermally neutral environment. Extra activity and cold thermogenesis are then considered additional functions, and thus maintenance is independent of the environment (Whittemore, 1976). The maintenance requirements for energy and protein, according to ARC (1981), are:

$$\text{Energy} \quad ME_m = 0.719.W^{0.63} \qquad \text{MJ ME/day} \qquad (24)$$

$$\text{Protein} \quad CP_m = 0.0009375.W^{0.75} \qquad \text{kg protein/day} \qquad (25)$$

where W, is the liveweight of the animal. The energy requirement of the pig is expressed in terms of feed metabolisable energy content (FMEC), and the protein requirement in terms of feed protein content (FPC):

$$FPC = DCP.V.FCPC \qquad \text{kg of protein/kg of feed} \qquad (26)$$

where DCP is the digestibility of crude protein, FCPC is the feed crude protein content in kg/kg of fresh feed and V, is the biological value of the protein in the feed. The V value can be obtained from the content of essential amino acids, either by use of an essential amino acid index (eg. the ideal protein index; ARC 1981) or by a chemical score (Whittemore and Fawcett, 1976). The FPC measurement is similar to the term 'effective protein' which was used by Emmans and Oldham (1988), relating to the first limiting amino acid.

## 2.3 A THEORY OF CONDITIONS WHICH ARE NON-LIMITING TO GROWTH

### 2.3.1 The Desired Feed Intake

An important quantity, called the desired feed intake (DFI) can now be defined. It is the rate at which the animal needs to eat its feed in order to satisfy its requirement for the first limiting feed resource and it is assumed to be the rate at which the animals seeks to eat the feed:

$$DFI = R_1/C_1 \qquad \text{kg/day} \qquad (27)$$

where $R_1$ is the requirement (in units per day) for the first limiting feed resource and $C_1$ is the feed content (in units per kg) of the first limiting feed resource. If the feed intake is sufficient to provide the first limiting resource, then all of the others will be provided in excess of the requirement. If energy is the first limiting resource, and the animal achieves its DFI, then it will attain its growth plan. If energy is not the first limiting resource and DFI is achieved, the animal will eat excess energy which, it is suggested, will be converted to extra lipid. Several factors may constrain the actual feed intake (FI) to a level below the desired feed intake. The most common of these constraints are feed bulk (particularly for ruminants on forage based feeds) and the ability to lose heat (especially for monogastrics on highly digestible, imbalanced feeds), and these will be discussed later.

For the sake of simplicity, it is assumed that the minerals and vitamins are always in abundance in the feed, and that feed intake (FI) supplies only energy and protein.

Therefore:

| | | | |
|---|---|---|---|
| energy supplied by the feed is | FI.FMEC | MJ/day | (28) |
| protein supplied by the feed is | FI.FPC | kg/day | (29) |

The metabolisable energy (ME) supplied by the feed is either retained in the body (ER) or lost to the environment as heat (HL), so that:

$$FI.FMEC = ER + HL \qquad MJ/day \qquad (30)$$

If energy is retained in the body only as protein and lipid (with the small amounts of carbohydrates being ignored), then we have:

$$ER = h_p.PR + h_l.LR \qquad MJ/day \qquad (31)$$

where $h_p$ and $h_l$ are the heats of combustion for protein and lipid respectively, MJ/kg, and PR and LR are the protein and lipid retentions, kg/d, respectively. Substituting equation (31) into equation (30) leads to:

$$FI.FMEC = h_p.PR + h_l.LR + HL \qquad MJ/day \qquad (32)$$

Equation (32) must be obeyed by the animal, as its potential for change in its heat storage by changing its body temperature is limited. If the quantities on the right hand side of this equation can be predicted, and FMEC is given (or calculated from the digestible energy content of the feed, DEC (ARC, 1981)) then feed intake can be predicted. The steps of predicting the components of equation (32) are:

(i) The amount of heat that can be lost to the environment (HL) is a function of the environment and the size of the animal alone, with heat loss assumed to be directly proportional to metabolic body weight (Holmes and Close, 1977; Close, 1987). On *ad libitum* feed, it is assumed that the heat loss (HL) is given by:

$$HL = (a + b\,(38 - T)).W^{0.67} \qquad MJ/day \qquad (33)$$

The above equation, where $W^{0.67}$, is the metabolic body weight and T, is the house temperature in $^{o}C$ (with the body temperature taken to be $38^{o}C$) was suggested by Emmans (1981) and an analogous equation was favoured by Close (1988). The values a and b, are constants and can be regarded as being independent of the environment and feed composition. Emmans (1981) suggested that the constants a and b, reflect the insulation value of an animal's coat, and therefore they are functions of the degree of maturity (Close, Heavens and Brown, 1981).

(ii) The following arguments are those of ARC (1981). Heat is produced (HP) by the various body functions. Work is needed to maintain the animal in a steady state; if all the energy of the feed is used to perform this work then all the metabolisable energy ingested will appear as heat. The synthesis of protein from amino acids requires work to be done and heat is also produced as a result. It is suggested that the work of maintenance ($ME_m$) includes that due to protein synthesis at maintenance, and that any protein retained (PR) above maintenance produces heat at the rate $w_p$, MJ/kg of protein retained. Similarly, lipid retention (LR) also involves work and hence heat production, at the rate $w_l$, MJ/kg of lipid retained. Therefore, the heat produced by the various body functions can be expressed by the equation:

$$HP = ME_m + w_p.PR + w_l.LR \qquad MJ/day \qquad (34)$$

When the environment is thermally neutral, the heat produced will be the thermoneutral heat loss:

$$HP = HL \qquad (35)$$

(iii) Protein is needed for maintenance and for protein growth (PR). The protein retention depends only on the supply of protein up to the potential rate. Above maintenance the feed protein eaten is assumed to be used for protein growth with an efficiency, $e_p$. Therefore:

$$PR = e_p\ (FI.FPC - CP_m) \quad kg/day \quad (\text{subject to } PR<PR_{max}) \qquad (36)$$

or $$FI.FPC = CP_m.\ 1/e_p.\ PR \quad kg/day \qquad (37)$$

The maximum protein which can be retained per day ($PR_{max}$) is the same as the potential protein gain described in Chapter I.

(iv) The desired lipid gain ($LR_{des}$), which is determined by the pig's genotype, is strictly associated with the potential protein gain, as it was described in Chapter I. Any lipid retained above $LR_{des}$, reflects the attempt of the animal to achieve its potential growth and depends only on the feed composition and the environment.

### 2.3.2 A Prediction of Feed Intake

The above arguments and values of the constants have been incorporated into a FORTRAN program, called the Feed Intake Model, which is detailed in Appendix 1.

The inputs to the model are:

Environment : house temperature, T, in $^oC$

Feed composition: feed digestible energy content, DEC, in MJ per kg of fresh feed, and

feed crude protein content, FCPC, in kg CP per kg of fresh food.

Genotype: the growth rate parameter, B, per day
the mature protein weight $P_m$, or MPMAS, in kg
the lipid to protein ratio at maturity, $LPR_m$, and
the allometric exponent, c, which relates the lipid to protein during potential growth

Current state: Liveweight at the start, W, in kg. The relationship between liveweight and protein weight at the start, P, was estimated to be P = 0.16 W, which is close to the relationship suggested by Wood and Groves (1965).

The values treated as constants in the model are:

Digestibility of the crude protein of the feed, DCP = 0.9; biological value of the protein, V = 0.8; efficiency of protein utilisation above maintenance, $e_p$ = 0.85 (Fisher, Morris and Jennings, 1973); protein heat of combustion, $h_l$ = 39.6 MJ/kg lipid (ARC, 1981), work of protein retention, $w_p$ = 20.2 MJ/kg protein (ARC, 1981); and work of lipid retention, $w_l$ = 14.9 MJ/kg lipid (ARC, 1981).

The equations used are:

| | |
|---|---|
| maintenance requirement for energy | $ME_m = 0.719.W^{0.63}$ |
| maintenance requirement for protein | $CP_m = 0.0009375.W^{0.75}$ |
| feed metabolisable energy content | FMEC = DEC(0.997-0.189 FCPC) |
| feed protein content | FPC = DCP.V.FCPC |

| | |
|---|---|
| energy supplied by the feed | $FI.FMEC = ER + HL$ |
| energy retained in the body | $ER = h_p\ PR + h_l.LR$ |
| heat lost to the environment | $HL = (0.25 + 0.06\ (38 - T))W^{0.67}$ |
| protein supplied by the feed | $FI.FPC = CP_m + 1/e_p.PR$ |
| heat produced by the body functions | $HP = ME_m + w_p.PR + w_l.LR$ |
| maximum protein retention | $PR_{max} = B.P.\ \ln (P_m/P)$ |
| desired lipid retention | $LR_{des} = PR_{max}\ LPR_m.\ c.\ (P/P_m)^{c-1}$ |

The above equations form an algorithm which predicts the rates of feed intake, body protein and lipid gains per day, for a pig of a certain genotype, at a weight at the start of the day, when it is given free and continuous access to a feed of a given composition (protein and energy contents) in an environment at a temperature $T^oC$. The possible outcomes of the model, in relation to feed intake, protein and lipid gains, are shown in Table 2.1. The model was designed to predict the outcomes of experiments where pigs are fed on single feeds of varying protein:energy ratios, as in the experiments described subsequently. However, the model does not predict feed intake, and consequently protein and lipid gains, of pigs previously given access to a restricted amount of feed. The problems of predicting the feed intake of such pigs is discussed in detail in Chapter IV.

### 2.3.3 Tests of the Rule of Feed Intake

The model is based on the idea that animals seek to eat for the first limiting feed resource (Emmans, 1981). If the first limiting feed resource is other than energy, then the animal will seek to eat more energy than it needs in order to attain its potential protein growth; the excess energy will be converted to extra lipid. This assumption is demonstrated in the two hypothetical examples of prediction of feed intake, shown in Figure 2.1. Pigs of 20 kg liveweight were given *ad libitum* access to feeds of varying protein content (0.12, 0.16, 0.20, 0.24, 0.28 and 0.32 g CP/kg fresh feed respectively) but with the same digestibility energy of 16 MJ/kg fresh

TABLE 2.1 The possible effects, of nutrient supply and environmental temperature, on feed intake, protein retention and lipid retention

| | Nutrients non-limiting | Nutrients limiting |
|---|---|---|
| Environment non-limiting | (i) Desired feed intake (DFI)<br>Potential protein retention ($PR_{max}$)<br>Desired lipid retention ($LR_{des}$) | (i) Desired feed intake (DFI)<br>Potential protein retention ($PR_{max}$)<br>Increased lipid retention ($LR>LR_{des}$) |
| Environment limiting | (i) Constrained feed intake ($F1<DFI$)<br>Potential protein retention($PR_{max}$)<br>Reduced lipid retention ($LR<LR_{des}$)<br><br>(ii) Constrained feed intake ($F1<DF1$)<br>Reduced protein retention ($PR<PR_{max}$)<br>Reduced lipid retention ($LR<LR_{max}$) | (i) Constrained feed intake ($F1<DF1$)<br>Reduced protein retention ($PR<PR_{max}$)<br>Increased lipid retention ($LR>LR_{des}$)<br><br>(ii) Constrained feed intake ($F1<DF1$)<br>Reduced protein retention ($PR<PR_{max}$)<br>Reduced lipid retention ($LR<LR_{des}$) |

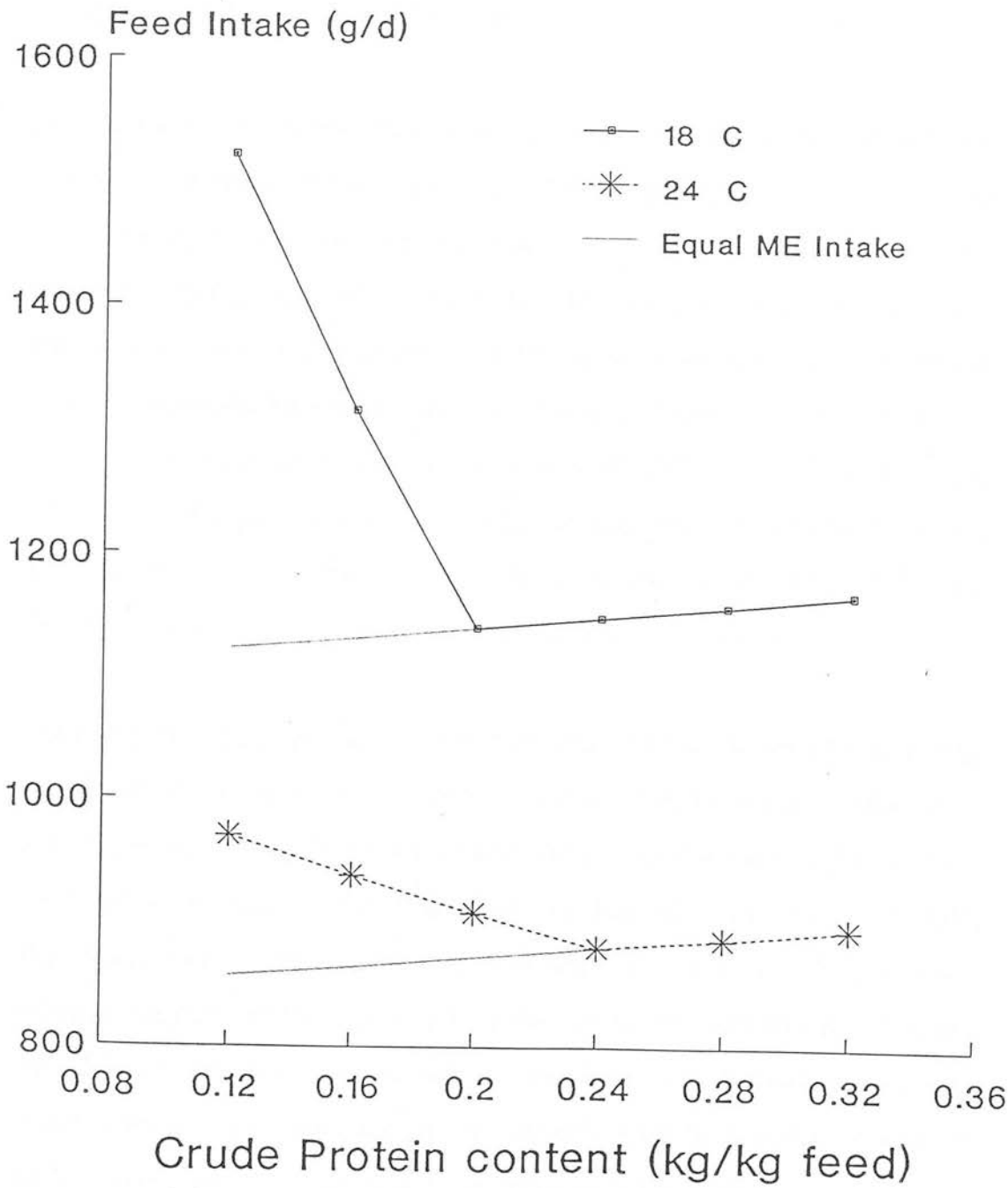


Figure 2.1 Predictions of feed intake by the Feed Intake Model, for pigs given access to feeds of the same digestible energy but different crude protein contents at two different ambient temperatures.

feed. Feed intake was predicted at two house temperatures (18 and 24°C respectively). The genetic variables of the pigs were taken to be: the growth rate parameter, B = 0.015 per day, the protein weight at maturity, $P_m$ = 40 kg, the allometric exponent relating lipid to protein during potential growth, c = 1.65, and the lipid to protein ratio at maturity, $LPR_m$ = 2.5.

At 18°C the model predicted that the pig met its requirements on the feed with 0.20 kg CP/kg and had a DFI of 1053 g/day. For any protein content above 0.20 kg CP/kg the pig ate equal amounts of metabolisable energy. However, as the protein content of the feed was reduced below 0.20 kg CP/kg, the feed intake increased substantially to attempt to compensate for the decline in the feed protein content; the excess of metabolisable energy intake resulted in an increased lipid retention. A similar picture appeared at a house temperature of 24°C, but the increase in feed intake, which followed the decline in feed protein content below 0.24 kg CP/kg, was not as spectacular as at 18°C. The animals on the low protein feeds at 24°C were limited by the amount of heat that could be lost in the environment.

The ability of the rule to predict actual feed intake can now be tested qualitatively, by experiment. It has often been demonstrated that 'animals eat for energy', since experiments on diluting feed with an inert filler showed a constant intake of the 'feed' and an increased intake of the filler with increasing dilution (Adolph, 1947; Cole, Duckworth and Holmes, 1967a, b; Owen and Ridgman, 1968). This proposition is better substituted by 'the animals eat for the first limiting feed resource' (Emmans, 1981), since the predictions of the model are consistent with observations that energy intake increases and animals get fatter on protein deficient feeds in short term assays. Such effects have been shown in experiments with sheep (Ranhorta and Jordan, 1966), chickens (Kirchgessner, Roth-Maier and Gerum, 1978) and pigs (Stamataris, Emmans, Hillyer and Whittemore, 1986). Their data, presented in Table 2.2, shows an increase in the feed intake and an increase in the feed conversion ratio following

TABLE 2.2 **The feed intake and growth of sheep, chickens and pigs given ad libitum access to single feeds of different crude protein (CP) content**

| Species | CP content of the feed (g/kg fresh weight) | Feed Intake (g/day) | Liveweight Gain (g/day) | Feed Conversion Efficiency (g feed/g gain) |
|---|---|---|---|---|
| Sheep[1] | 110 | 1239 | 300 | 0.242 |
| | 140 | 1280 | 320 | 0.253 |
| | 165 | 1170 | 300 | 0.256 |
| Chickens[2] | 160 | 146 | 66 | 0.450 |
| | 210 | 136 | 68 | 0.505 |
| | 260 | 133 | 68 | 0.510 |
| Pigs[3] | 150 | 574 | 293 | 0.510 |
| | 252 | 510 | 449 | 0.880 |

Data Sources : 1. Ranhotra and Jordan (1966)
2. Kirschgessner, Roth-Maier and Gerum (1978)
3. Stamataris *et al* (1986)

the introduction of a feed of low protein content. Although it is less clear that similar effects on feed intake occur where a feed is deficient in a vitamin or mineral, the results of Taylor (1970) with hens fed on feeds with different calcium contents give strong evidence for the generality of this rule. The hens had a substantially higher feed consumption on the low-calcium than on the high calcium feed; the latter was prepared by adding calcium carbonate to the low-calcium feed in order that the feed intake data was comparable for both feeds on a protein and energy basis.

The idea that the house temperature plays a significant role in the attainment of the desired feed intake, is strongly substantiated by the results of Andik, Donhoffer, Farkas and Schmidt (1963). At room temperature (20-25$^{o}$C), rats offered *ad libitum* a feed with 0.04 kg CP/kg feed, ceased to grow and died because they failed to obtain enough nutrient before heat loss constrained their intake. When the same feed was offered to the rats at 5$^{o}$C ambient temperature, they doubled their feed intake, achieved a higher nutrient intake and were able to grow well since the heat loss was not any more a constraint. Similar effects were demonstrated by Gibb and Penning (1972) on the growth and feed intake of lambs at three different temperatures. In all cases animals were able to achieve higher protein growth rates on protein deficient feeds at lower house temperatures.

### 2.3.4 Improvement of the Model

The predictions of the feed intake model agree, at least qualitatively, with the outcomes of some real experiments. The quantitative predictions of the model will be in error if:

(a) the concepts of the theory are put into inadequate functional forms, or

(b) the values chosen for the constants of the equations are inappropriate or have been wrongly identified as constants.

The major concern is expressed for the following components of the model. The digestibility of the crude protein of the feed, DCP, and the biological value for protein, V, are certainly not constants. The description of the current state by liveweight alone and the use of a simple energetic scale are limitations of the model. Feed bulkiness is ignored and it is assumed there are no effects of excess of nutrient intake or toxins in the feed. Further consideration of these components is desirable before the model is used over a wider range of either feed qualities or environments.

(i) The assumption that the digestibility of the crude protein, DCP, and the biological value for protein, V, are constants for the types of feeds used in the experiments of this thesis will be justified later. However, if the model is used over a wider range of feed qualities it is suggested that the DCP and V values are treated as inputs of the model since both can vary accordingly to the feedstuffs used for the formulation of the feed.

(ii) The equations that estimate maintenance requirements are expressed in the models as functions of the liveweight of the animal. However, in the previous chapter it was suggested that liveweight alone was an insufficient descriptor of the state of the animal and the weight of protein, P, or remainder, R, should be used instead. Taylor (1970) produced a general rule for scaling maintenance (defined as MN):

$$MN_{ijk} = M_i.A_j^{-0.27} (We_k) \qquad \text{units/day} \qquad (38)$$

where the i, j, k refer to the ith resource, the jth genotype and the kth equilibrium weight (the weight that is eventually maintained). However, since the composition of immature animals may vary substantially and they

are rarely in equilibrium, a version of Taylor's (1970) rule to deal with this variation was proposed by Emmans and Fisher (1986):

$$MN_i = M_i.P_m^{-0.27}.\ P \qquad \text{units/day} \tag{39}$$

where $P_m$, is the mature protein weight and P, the protein weight. The above maintenance scaling rule implies that no energy is needed to maintain body fat, on regular feeding (or that it is so low that it may be ignored) (Kulesza, 1986). This assumption is justified by the findings of Metz and Decker (1981), that for pigs fed every 12 hours, body lipid had a zero rate of turnover.

Emmans and Oldham (1988) suggested that, in a thermally neutral environment, the values of $M_i$ for energy is 1.63 MJ/unit and for protein is 0.010 kg protein/unit. These values were estimated from published experiments (eg. Forbes, Braman and Kriss, 1928; 1930; Hakansson, Eriksson and Svensson, 1978a; b) and were found to be constants for pigs, chickens, sheep and cattle.

The equation that estimates heat loss (HL) was also a function of the animal's liveweight (in the case of the model a function of the metabolic body weight). Such an equation ignores the effects of the body state on heat loss. It is well appreciated that the state of the animal influences heat loss (Close, 1981) and this has often led to the use of two different equations, for example, for fat and thin shows (Holmes and Close, 1977). These problems may be able to be overcome if heat loss is also expressed as a function of the protein weight of the animal, although here lipid weight may be relevant.

(iii) The ME system proposed by ARC (1981) treats all of the metabolisable energy available to the body as equal irrespective of its source (the digestible components) or how it is utilised. Although there are no important problems with the ME yielded from digested carbohydrates, there are problems with both protein and fat. For example, when digested protein is catabolised there is an increased loss of energy as urea into the urine and a lower ME should be attributed to the feed; this effect is allowed for in the model. In addition, the animal uses energy in the formation of urea, so reducing that available for productive functions (Hamilton,1965). Similarly, the losses of energy in the metabolism of absorbed nutrients vary not only with the source of energy, but also with the final uses to which energy is put. The energy of absorbed fat is used more efficiently for the deposition of body fat than is that from carbohydrate (ARC, 1981).

Although ARC (1981) is doubtful that any corrections of ME for the digested protein and fat is worthwhile, there are equations which correct the ME of the feed. Emmans (1984) has used the term effective energy (EE) for a corrected energy scale:

$$EE = ME - 4.672.DGCP - 3.80.FOM + 12\ k_x.DEE \quad MJ/kg \qquad (40)$$

where DGCP, is the digested crude protein in kg/day, FOM, is the faecal organic matter in kg/day, DEE, is the digested ether extract in kg/day and $k_x$, is the proportion of the DEE directly retained.

(iv) The model does not take account of the effect of feed bulk intake. This is because pigs are usually fed on a digestible, high quality feed with a range of dietary energy content from 12.5 to 14 MJ DE per kg (Henry, 1984) so that bulk constraints rarely apply. Nevertheless, the model should not preclude

the possibility that a feed may be so bulky that the animal is unable to meet its desired feed intake through feed bulk. In this case the animal will try to eat enough of a given feed to satisfy the requirement for the first limiting resource to growth. Therefore, taking animals with a similar capacity for bulk and ability for growth, the feed intake will initially increase as the proportion of the bulk in the feed increases (Cole *et al*, 1967a; b). At a critical bulkiness, feed intake will be maximised, when bulk intake reaches the bulk capacity of the animal. From this point, as bulkiness is increased further, feed intake will be reduced, as the animal's intake is constrained by its capacity for bulk.

(v) The effects of toxins on the general health and feed intake of animals is a broad and complex topic. At one end, poisons such as strychnine and cyanide have immediate and lethal effects, whilst other toxins such as lead can be stored in the body without having any immediate effect on the animal. In general, an animal has several options when it is faced with an intake of a toxic material: (a) it can refrain from absorbing it, (b) it can excrete it, (c) it can change it to a less harmful form, and (d) it can store it (Duffus, 1980). From these four mechanisms (c) may increase with exposure, while (b) and (d) probably have some upper limit. If the way in which the animal deals with a toxin can be understood and quantitatively described, it would be possible to predict at what level a toxin in the feed will affect feed intake.

Clark, Harvey and Humphreys (1981) have suggested that, for the most part, toxins (other than lethal toxins) in feeds result in a fall, or temporary cessation in feed intake, whilst the animal excretes, degrades or immobilises the offending substance. In this way, a sufficient excess of an essential nutrient (eg. protein) can act as a toxin, since it causes a transient fall in feed intake (Harper, 1974). The rate of feed intake will be restored to that of the

desired feed intake, only after the excess of amino acids has been deaminated and excreted from the body.

## 2.4 NON-LIMITED GROWTH ON A SINGLE FEED

The predictions of the Feed Intake Model can now be compared with the feed intake data of Stamataris *et al* (1985) in order to justify the use of their liveweight data in the analysis of the potential growth of pigs in Chapter I. The pigs in that experiment were offered free and continuous access to a single feed which contained 225 g CP/kg fresh feed, was calculated to yield 15.3 MJ DE/kg and was abundant in minerals and vitamins; the house temperature was approximately 24$^{o}$C throughout the experimental period. The model predicted that those pigs, at a liveweight of 9.3 kg (which was the average liveweight) could achieve their potential protein growth and desired lipid growth by consuming 532 g per day (males) and 538 g per day (females) of that particular feed, at 24$^{o}$C house temperature. The actual feed intakes were respectively 506 (s.e. 17.8) and 513 (s.e. 12.7) g per day and not significantly different from the values predicted by the model (compared with a t-test).

Additional tests of the model are presented in Experiments 1, 2, 3 and 4, where pigs were given free and continuous access to single feeds which varied in their protein:energy ratios. In these experiments the model was also used to predict how the requirements of the pigs change as they grow. The desired protein:energy ratio in the feed is expected to fall as the pigs mature. This is mainly the result of the lipid gain that contributes an increasing proportion to the gain of the empty body, as the animal grows (as it is described by the allometric relationship), and the increased energy cost for maintenance as the pigs increase in size. In addition, the protein growth rate reaches a maximum at a degree of maturity of, $P_m/e$, or $u = 0.367$ and then it declines towards zero (Chapter I).

Such a change in the desired protein:energy ratio in the feed can present a problem in experiments that are done over a period of time, during which the state of the animals involved changes. If a pig is given *ad libitum* access to a single feed, the feed may change from being inadequate to adequate and then to abundant during the course of a single experiment. Similar problems may arise when the required feed balance arises above that supplied in the feed, during the occasion of increased environmental hotness.

Therefore, a pig fed on a single feed may not have the chance to choose an ideal and changing feed balance and it can become constrained or have an excess of nutrient intake. Consequently, it would be safer, if the non-limiting conditions for growth are to be met continuously, if the pig were to be introduced to a range of feeds which differ substantially in their protein:energy ratios and left to choose by itself its own diet. It is possible then, that the animal will be able to choose a diet that meets its requirements at a time, being in a given state.

## 2.5 THE PROVISION OF NON-LIMITING CONDITIONS ON A SET OF FEEDS

When an animal is given free and continuous access to two or more feeds, and hence given a choice (therefore, this system will be called choice-feeding), it has to 'decide' how much of each to eat and consequently what the composition of its diet should be. On a single feed the animal has no degrees of freedom for its diet composition, it can only decide the amount of feed eaten. With two feeds, it has one degree of freedom (and in general with n feeds it has (n - 1) degrees of freedom) with which diet choice can be exercised.

The choice-feeding approach was firstly adopted by Stabler (1911) and Evvard (1915a; b). They offered growing pigs *ad libitum* access to seven feeds, as a

choice:whole grain, meat meal, whole oats, charcoal, oilmeat, limestone and salt. They expected that pigs would be able to choose a non-limiting diet, since they considered 'the appetite of swine a reliable indicator of physiological needs'.

The pigs on these experiments performed well; some of them grew faster than any previously reported at the Iowa Agricultural Station. Evvard (1915a) stressed the finding that as the pigs grew, they maintained a varying balance between protein and energy in their total feed intake, by changing the proportion of each of the feeds in their selected diet. When they were young, the pigs selected a diet with a high ratio of protein:energy, which declined (by eating a smaller proportion of the protein-rich feed) as they became larger. On the basis of these results Evvard (1915a) advised that the choice-feeding should be adopted in favour of single feeding since:

> 'it enables and encourages maximum development: in other words actually permits the inherited specifications to be fulfilled to all intents and purposes'.

If an animal is able to choose an ideal and changing nutrient balance when it is offered *ad libitum* access to more than one feed, such a feeding system would have obvious advantages over the conventional single-feeding system in facilitating potential growth. Animals of different genotypes, at different states and in different environments, will have the opportunity to choose a non-limiting diet and consequently meet their requirement, at a time, for energy and other nutrients, when they are given a choice to a range of feeds which differ (substantially) in their nutrient:energy ratios (Emmans, 1977). This feeding system could also account for the problems presented by the variability in the nutritional contents of different batches of an ingredient (Emmans, 1975).

The problem then is to find the rules, if any, by which an animal chooses its diet composition. If there are no rules and the choice of animals is based on simple individual preferences, such as the taste or positional preferences (as it was suggested by Scott and Quint, 1946), it is clear that the outcome of choice-feeding experiments can not be predicted. Emmans (1979) suggested that the evidence from the literature on choice-feeding experiments with poultry was that these animals used rules in selecting their diet, and that further experiments were needed if these rules were to be defined more fully.

The next section of this chapter proposes a general theory of diet selection in the form of simple rules. Each of the rules asserts what choice the animal should make if its behaviour is to be consistent with the notion of evolutionary fitness. Subsequently, the evidence from experiments is used to test the validity of these rules.

## 2.6 A THEORY OF DIET SELECTION

In accordance with Evvard's (1915a) observations that:

> 'The lower animals select with unerring precision, as long as they are in a natural environment, from the materials around them those best fitted for their wants, and they do this by distinctive discernment inherited from along lines of naturally selected ancestors'

a domesticated animal is assumed to have the desire to fulfil its growth plan and also to have the ability of discrimination (Lat, 1967). Therefore, when an animal is given *ad libitum* access to a set of feeds it is expected to search amongst all the feeds on offer until it succeeds in choosing a non-limiting diet for growth. It is also suggested that any prevalent relaxation, due to domestication, of the ability of the animal to

select an adequate diet, is minimal in relation to the rigorous selection which had operated on the wild ancestor for thousands of years (Cropper, 1987).

In an analogous way to single feeding, non-limiting growth can only be achieved if the diet satisfies the three conditions:

(a) perfectly balanced ratio of nutrient:energy

(b) is not too bulky, and

(c) is not toxic.

Types of diet selection experiment fall into three categories corresponding to the above three conditions. For the sake of simplicity, each experiment is regarded essentially as a choice between two feeds.

There are two types of feeds to be considered in respect to the nutrient:energy ratio of the feed: a high nutrient:energy (non-limiting) and a low nutrient:energy (limiting) feed. The combination of the feeds provide three types of pairs to be considered; the two feeds differing in only one nutritional variable at a time (eg. two feeds with different protein contents). The suggested rules are:

(i) When an animal is given a choice between a feed with a high nutrient:energy ratio and a feed with a higher nutrient:energy ratio, it avoids completely the more abundant feed, since it seeks to minimise excess nutrient intake.

(ii) When an animal is given a choice between a feed with a high nutrient:energy ratio and a feed with a low nutrient:energy ratio, it chooses a non-limiting combination of the two feeds and avoids excess nutrient intake.

(iii) When an animal is given a choice between a feed with a low nutrient:energy ratio and a feed with a lower nutrient:energy ratio, it consumes only the less-limiting feed, and therefore minimises the deficit in nutrient intake.

There are two more rules to be considered in respect of the bulkiness and toxicity of the feed. These are:

(iv) When an animal is given a choice between two feeds that differ in their bulkiness, it avoids the more bulky feed and consequently maximises the rate of feed intake.

(v) When an animal is given a choice between a toxic and a non-toxic feed, it favours the non-toxic feed and avoids the toxic one completely.

The above five rules allow the prediction of the outcome of experiments where animals are given a choice between feeds which differ in one nutritional dimension, but they do not cover more complex situations. When an animal is given a choice between two feeds which differ in more than one nutritional dimension, it may select a diet according to its priorities for growth (Chesters and Quarterman, 1970).

### 2.6.1 Tests of the Theory

**Rule (i).** Musten, Peace and Anderson (1974) offered rats free and continuous access to two feeds with similar ME yield but different levels of CP. Both feeds were excessive in protein content, a fact which was demonstrated when offered singly to similar test rats. Similarly, Cropper (1987) offered an analogous choice of two abundant in CP feeds to sheep. In both experiments the animals avoided almost completely the more abundant feed and therefore minimised their excess of nutrient intake. The small amounts which were eaten from the more abundant feed (which were not significantly different from zero consumption in Cropper's (1987)

experiment) are likely to have represented the consumption of this feed during the early days of the experiment.

**Rule (ii).** In the majority of the diet selection experiments reported in the literature, animals were offered a choice between a feed with a low nutrient:energy ratio and a feed with a high nutrient:energy ratio. Most authors conclude that animals are able to choose a non-limiting combination of the two feeds which permits them to express their potential for growth.

Rats and mice have been the favourite animals for these types of experiment. Their ability to select a non-limiting diet has been demonstrated so repeatedly (Osborne and Mendel, 1918; Mitchel and Mendel, 1921; Richter, Holt and Barelare, 1937, 1938; Musten *et al*, 1974; Hill, Gastonway and Collier, 1980) that it has often been taken for granted (Overmann, 1977). Other laboratory animals have also shown the ability to discriminate between feeds of different nutritional value (Norway wild rats by Griffiths and Harmon, 1954 and hamsters by Di Battista, 1987).

In poultry, the early experiments of Pearl and Fairchild (1921), Rugg (1925), Banta (1932), Graham (1932), Funk (1932) and Stearns and Hollander (1939) have demonstrated the ability of chickens and pigeons to choose a non-limiting diet when given a choice between a wide range of feeds. More recently, the method of offering a choice between a whole cereal and a high protein 'balancer' has been exploited as a potential method of feeding in intensive poultry production. The demonstrable ability of poultry to balance their diet when fed in this way (for example, Emmans, 1975, 1977; Rose and Michie, 1982) has led to considerations of using this system in everyday practice (Tauson and Elwinger, 1986). Hens have also shown the ability to select an adequate proportion of a given mineral (usually calcium) in their diet, when they are given a choice between a mineral-rich feed and a mineral-deficient one (Hughes and Wood-Gush, 1972; Chah and Moran, 1985).

Ruminants, however, have rarely been used in controlled environment diet selection studies. This may reflect, firstly, the tendency not to allow them to grow at their potential and secondly, with ruminants, research emphasis has been placed on the diet selection made by grazing animals in the field (Provenza and Balph, 1987). The only complete study on the diet selection of sheep in a controlled environment is the series of experiments by Cropper (1987), where sheep were allowed to choose from feeds of different CP contents. These experiments have unequivocally demonstrated the ability of sheep to select a diet which supported their growth potential and minimised excess of nutrient intake.

**Rule (iii).** Only in few experiments animals have been offered a choice between two limiting feeds. This has happened either accidentally (Savory, cited by Hughes, 1979; Pamp, Goodrich and Meiske, 1977), when the investigators had underestimated the requirements of the animals, or intentionally (Musten *et al*, 1974; Holcombe, Roland and Harms, 1976). It is well appreciated that a choice between two limiting feeds is not useful when the production potential is to be observed; however, such a choice is of a major ecological interest, since animals in nature are often faced with a similar situation.

Two of the examples from the literature (Musten *et al*, 1974; Holcombe *et al*, 1976) offer contradictory results. In the former study rats were given a choice between a feed with a low protein:energy ratio and a feed with a lower protein:energy ratio. The animals consumed the feed with the low protein:energy ratio and hence minimised the deficit in nutrient intake. However, when a similar choice was offered to hens (Holcombe *et al*, 1976) their choice was equally divided between the two feeds. Therefore, the lack of sufficient experimental evidence, on this type of choice, suggests that this rule remains to be proven.

**Rule (iv).** Experimental evidence which tests the rule on the choices made by animals between feeds with different bulkiness is also scarce. This is partly due to the fact that ruminants, for which the selection of a diet from bulky feeds is most commonly a problem, are not used in controlled environment studies. The most useful data comes from Cropper (1987) relating to sheep offered a choice between two bulky feeds, and from field observations on grazing ruminants by Krebs and McCleary (1984). Cropper (1987) offered to sheep a choice between two feeds abundant in protein, minerals and vitamins but different in digestibility and bulk density. Although his results were not conclusive, since a substantial amount of the bulkier feed was still consumed, Cropper (1987) suggested that animals favour the less bulky feed, especially when the desired feed intake is constrained by intake of the bulkier feed.

**Rule (v).** In the class of the experiments that offer a choice between a toxic and non-toxic feed can be listed all the experiments of poisoning-avoidance in rats performed by Garcia (eg. Garcia and Koelling, 1966; Garcia, McGowan and Green, 1972). In all these experiments the rats were successful in avoiding the toxic feed and its consequences completely. A substantial amount of evidence also derives from experiments where rats were given a choice between a protein-free feed and one totally deficient in one amino acid (Harper and Rogers, 1966; Leung, Rogers and Harper, 1968). Since none of the heavy concentrations of amino acid in the deficient feed can be used by the animal (since the feed lacks completely an essential amino acid for tissue synthesis) the deficient feed acts as toxic. The animal has to deaminate all the amino acid it consumes from the deficient feed. In all these types of experiments (Harper and Rogers, 1966; Leung *et al*, 1968) the rats avoided the deficient feed (and hence toxic) completely.

### 2.6.2 Apparent Contradictions to the Theory

Not all investigators have suggested that animals can choose what they need and avoid what they do not. A substantial number of investigators (Neven, 1927; Kon, 1931; Scott, 1946; Scott and Quint, 1946; Young, 1967; Cowan and Michie, 1977; Panip *et al*, 1977) have concluded that the animals used in their experiment were unable to do so and that: 'the appetites [of animals] are often fickle and unpredictable ... Appetites may be trivial in origin .... Nutrition based on appetite is not universally successful'. (Anon, 1944).

However, a closer examination of these experiments reveals that they probably belong to the class of experiment where the animals were not truly given the necessary choice. For example, in the experiments by Kon (1931), Scott and Quint (1946) and Cowan and Michie (1977) the animals were given a choice between two feeds, the quality of which was not tested independently by feeding them singly to animals. Consequently, the idea that the animals were not given a choice between two feeds, a combination of which could be a non-limiting diet, remained an untested possibility.

The need for control treatments (independent single-feeding) has been very clearly demonstrated in the experiments by Mu sten *et al* (1974). When rats were given a choice between two feeds with different levels of casein, they were able to choose a non-limiting diet which supported their potential growth. However, when similar rats were offered a choice between gluten-based feeds they grew very slowly. These results could be used to provide support that choice-feeding experiments are often inconclusive and their outcome unpredictable. Fortunately, Musten *et al* (1974) had employed all the control single feeding treatments, and the evidence from them demonstrated that gluten-based feeds could not support the potential growth of rats, even when they were fed singly. Therefore, it was not the inability of the rats to

select a non-limiting diet, but the fact that they were offered a choice between limiting feeds that prevented them doing so.

Cropper (1987) criticised the frequent omission of control treatments in many published choice-feeding experiments, which was often made in the interest of economy. Musten *et al* (1974) tested five casein-based, five gluten-based and one protein-free feeds, and therefore the complete experimental programme would have included twenty one treatments for the casein-based feeds (that is, the six feeds offered singly and fifteen combinations of feed-pairs), and twenty treatments for the gluten-based feeds. They used only a sub-set of these treatments, but they also selected the treatments which could provide support for the theory that animals are able to select a diet which supports their potential growth, particularly from the data of the single-fed treatments.

## 2.7 CHOICE-FEEDING OF PIGS

The success of Stabler (1911) and Evvard (1915a; b) which demonstrated the ability of pigs to select a non-limiting diet from a set of feeds (a wide range of feedstuffs), led Morrison (1937) to conclude that: 'fortunately pigs show a remarkable ability to balance their rations'. Morrison (1937) also offered additional evidence when he reviewed a series of experiments where pigs were offered a choice between a cereal (usually corn or wheat) and a protein supplement (eg. tankage). In all these experiments pigs consumed enough supplement to balance their ration and they gradually chose a smaller proportion of the supplement as they grew older.

Thirty years later, Braude (1967) reviewed another set of choice feeding experiments conducted mainly in the USA and France (eg. Adams and Ward, 1957; Rerat and Henry, 1964; Holck and Trible, 1965) which appeared as short abstracts in the

Journal of Animal Science. The contradictory results of these experiments led Braude (1967) to the inconclusive suggestion:

> 'There are many reports pointing to better results with mixed feeds than with self-choice.... several reports indicate no difference in performance with the two methods of feeding ..... none giving superiority to the self-choice method'.

However, it is important to stress that the description of these experiments (the composition of the feeds used was not reported, each feed was not tested independently and the potential growth of pigs was not defined) did not always permit a comparison and interpretation of the results.

Finally, there is a third class of experiments, where pigs were offered a choice between a protein-free feed and a feed deficient in one amino acid (Robinson, 1974; 1975) or a choice between a 'complete' feed and one deficient in a single amino acid (Devilat, Pond and Miller, 1970). In both cases the pigs avoided the deficient diet and consumed either only the protein-free or the 'complete' feed.

Therefore, the experimental evidence lies in favour of the idea that animals select their diets, in a wide range of circumstances, according to the suggested theory of choice feeding. Animals faced with more than one feed used rules in selecting their diet; further experiments are needed to describe these rules more fully. In relation to pigs, Evvard's (1915a, b) experiments provide conclusive evidence for diet selection, but the use of choice-feeding as an alternative way of feeding the modern pig genotypes in exhibiting their potential growth has yet to be considered.

The experimental part of this chapter reports the findings of two experiments designed:

(i) to test the theory of choice feeding,

(ii) to examine the potential use of choice-feeding as a method of defining non-limiting conditions for the growth of pigs,

(iii) to test the Feed Intake Model, and

(iv) to examine the theory of providing non-limiting conditions on a single feed.

## 2.8 EXPERIMENT 1 : A TEST OF THE THEORY OF DIET SELECTION

### 2.8.1 Objectives

The experiment was designed to test ideas on diet selection and to assess their validity as descriptors of both the behaviour and the conditions which are non-limiting for the growth of pigs. Each pig was to be given free and continuous access to a pair of feeds which differed in only one nutritional variable. The variable chosen for this preliminary investigation was that of the protein:energy ratio, since it was considered to be a factor of major importance to the animal. In addition, a control series of single feeds of different protein:energy ratios tested the validity of the Feed Intake Model in predicting the change in the rate of feed intake when the crude protein content of the feed is reduced.

### 2.8.2 Propositions

(a) **Single-fed pigs**

P1 Pigs will increase their rate of feed intake, at a weight, as the protein content of the feed is decreased.

(b) **Choice-fed pigs**

The set of the propositions to be tested, which corresponded to the theory of Diet Selection in section 2.6 of this chapter, were:

P2 Pigs will choose between the feeds on offer in a directed manner.

P3 Pigs will not select their diet on the basis of the position of the feeds.

P4 Pigs will minimise an excess of nutrient (protein) intake.

P5 Pigs will select a diet of a certain composition, according to the protein contents of the feeds on offer.

P6 The protein content of the diet selected will decrease as the pigs mature.

### 2.8.2.1 Corollaries

(a) **Single-fed pigs**

C1 The rate of the increase of feed intake and the growth rate of the single-fed pigs will follow the predictions of the Feed Intake Model

C2 Pigs on a high protein:energy feed will grow at a rate set by their inheritance.

(b) **Choice-fed pigs**

Should propositions P2-P6 survive, the theory of diet selection predicts that the pigs will select a protein:energy balance in their diet such that energy is the first limiting feed resource for growth, in which case the following corollaries apply:

C3 All the choice-fed pigs will have a similar daily rate of total feed intake which is dependent upon their energy requirement and that predicted by the Feed Intake Model.

C4 Pigs, given the opportunity, will grow at a rate set by their inheritance.

### 2.8.3 General Materials and Methods

*Housing*. The experimental unit (Building No. 24, Easter Howgate Farm, Edinburgh School of Agriculture) was a portacabin consisting of two identical wings separated by a central work area. Each wing had its own heating, lighting and ventilation system, with a water supply serving the two opposing ranks of ten individual cages. Each cage had a slatted floor (61 x 103 cm) and was 59 cm high; the long sides were wire mesh (so the animals had visual contact with their counterparts) and the front and the back of the cage were sheet metal. Each cage contained one or two (according to the experimental procedure) galvanised metal troughs (15 x 15 cm, 53

cm high) and a nipple drinker gave free access to water. Underneath each trough a metal tray was placed, where feed spillage was collected. For the first and second experiments, there were 20 cages available to accommodate two troughs; their number was increased to 24 for the subsequent experiments. The position of these cages was randomised within each wing.

Four 100 watt light bulbs supplied each wing with a constant dim light and they were fully lit only when feed refusals and weights were recorded (approximately for three hours during the morning). Three probes in each wing, connected with a computerised system (AUTOLOG, time-temperature monitor) continuously recorded the ambient temperature, which was also monitored by minimum-maximum thermometers.

*Animals*. All the pigs were progeny of the Easter Howgate herd and were moved immediately after weaning (at 4 weeks of age) from the farrowing house into the individual cages of the experimental unit. These weaned pigs did not have any previous experience on creep-feed.

*Management : Pre-experimental period*. The weaned pigs were given free and continuous access to a high quality commercial feed: Oldacres - WS 248 MLC Early-wean Meal Pellets, containing 250 g CP/kg and 5g Intagen$^{R}$/tn. The house temperature was set at 28$^{o}$C initially, in an attempt to overcome the post weaning stress; it was then lowered according to the experimental plan. A preventive treatment of 4 ml Neftin (Smith and Kline; containing 50 mg furazolidone per ml) was given for 3 days to all animals. When severe diarrhoea was present, an additional dose of Kaogel (Park-Davis; containing 3 g light Kaolin and 65 mg Pectin U.S.N.F. per ml) was given only to the scouring animals. Pigs that died or became very ill from scouring due to colibacillosis during the pre-experimental period were replaced by animals from another litter.

During this period the pigs were weighed daily to the nearest 10 g on a Datamass 605-digital indicator (60 kg x 0.01 kg). They were fed once a day and the feed refusals and feed intakes were also recorded daily to the nearest 1 g on a weighing scale. Spillage losses for each individual were collected from the trays, weighed and their value was deducted from the calculated daily intake.

**2.8.3.1 Materials and Methods of Experiment 1**

*Animals*. The intention was to obtain 40 pigs, equal numbers for each sex, for the purpose of the experiment. However, a major outbreak of colibacillosis in the farrowing house restricted both the number of litters and the number of individual healthy pigs available. Instead, forty Cotswold Landrace x Large White pigs were obtained (unequal numbers for the two sexes) and moved into the individual cages.

*Feeds*. Three feeds with different crude protein (CP) levels (low (L), medium (M) and high (H)), but with similar energy yields, were formulated and made into pellets (Table 2.3)

The low protein feed (L) was formulated to be inadequate in crude protein to support potential growth, when offered *ad libitum* (ARC, 1981). Flaked maize, oatflakes and milk replacer were chosen as the major components of this feed. The high protein feed (H) was intended to be above the requirements of the pigs, and it was made by substituting herring meal, pruteen and some barley for the major ingredients of feed L. Pruteen is the commercial name of a protein of bacterial origin (marketed by the Imperial Chemical Industries Ltd, Agricultural Division, Billingham, Cleveland) and is produced in a continuous fermentation process by growing a micro-organism (Methylophilus methylotrophus) on methanol as the source of energy (ICI, 1981). Feed M was 0.5L + 0.5H and it had close to the required ideal protein content for pigs of similar age, suggested by ARC (1981). All three feeds

were intended to be non-limiting in minerals and vitamins, since the experiment aimed to test ideas concerning a pig's selection for protein, but feed H contained higher amounts of minerals (to maintain suitable ratios to protein). The chemical analysis of the three feeds is shown in Table 2.4.

*Methods : Pre-experimental period*. The pigs had a mean liveweight of 6.34 kg (s.d. 1.36) when they were moved into the cages. The scouring continued during this period and this resulted in a long pre-experimental period which lasted for 22 (s.d. 6) days, and the loss of six animals. Only four animals were replaced by pigs from another litter, due to the limited number of healthy replacements. The pre-experimental period ended when animals reached 12 kg liveweight. At this stage 38 pigs were available for the experimentation (23 females and 15 males).

*Experimental design*. The design was a complete two-way choice-feeding experiment using three feeds. This resulted in six treatments, which were: the three feeds fed singly (treatments L, M and H) and the three feeds as two-way choices (three possible pairs, treatments LH, LM and MH). The unequal numbers of pigs per sex created some problems in the allocation of the animals to treatments. Two male and four female pigs were randomly allocated in each treatment (apart from treatment M), taking account of age at 12 kg and with a restriction for litter origin. The three extra males were allocated between the single-feeding treatments (one to treatment H and two to M). The exact number of pigs and sexes per treatment is shown in Table 2.5.

The position of the feeds was randomised across pigs, and to test the proposition that pigs do not select their diets on the basis of the position of the feeds, the feed position was reversed only once, at 24 kg liveweight. The experiment ended when animals reached 30 kg liveweight.

TABLE 2.3 **The composition of the three feeds (kg/tn freshweight) used in Experiment 1.**

| Ingredient (kg/tn) | FEED L | M | H |
|---|---|---|---|
| Pruteen | - | 75 | 150 |
| Herring meal | - | 75 | 150 |
| Flaked maize | 250 | 125 | - |
| Oatflakes | 478 | 239 | - |
| Barley | - | 79 | 141 |
| Milk replacer | 185 | 333 | 480 |
| Molasses | 50 | 50 | 50 |
| PT10C Vitamin and Mineral supplement[a] | 5 | 5 | 5 |
| Vitamin E supplement | 6.5 | 8.5 | 10.5 |
| Salt | 2.5 | 2.5 | 2.5 |
| Dicalcium Phosphate | 23 | 8 | 11 |
| | 1000 | 1000 | 1000 |

a PT10C supplement (Nutrikem) contains (per kg supplement): Vit A, 3.0m iu; Vit $D_3$, 0.4m iu; Vit E, 3000 iu; Vit K, 300 mg; Vit $B_2$, 1000 mg; Pantothenic acid, 4000 mg; Thiamine, 300 mg; Nicotinic acid, 8000 mg; Vit $B_{12}$, 6.0 mg; Folic acid, 100 mg; Vit $B_6$, 400 mg; Zn, 20,000 mg; Cu, 35,000 mg; Fe, 20,000 mg; Mn, 10,000 mg; Co, 20 mg; I, 100 mg; Se, 20 mg.

TABLE 2.4 **The chemical analysis of the three feeds (g/kg fresh weight) used in Experiment 1**

| Component (g/kg) | FEED L | M | H |
|---|---|---|---|
| Digestible energy[a] (MJ/kg) | 15.6 | 16.3 | 16.8 |
| Dry Matter | 903 | 908 | 918 |
| Crude Protein (CP) | 131 | 225 | 332 |
| Lysine[b] | 6 | 15 | 23 |
| Ether extract | 71 | 79 | 96 |
| Ash | 63 | 67 | 90 |
| Crude fibre | 14 | 14 | 11 |

[ab] values calculated from feed tables

TABLE 2.5 **The design of Experiment 1**

| Treatment | n | Males | Females |
|---|---|---|---|
| a. Single-fed | | | |
| L | 6 | 2 | 4 |
| M | 7 | 4 | 3 |
| H | 7 | 3 | 4 |
| b. Choice-fed | | | |
| LM | 6 | 2 | 4 |
| LH | 6 | 2 | 4 |
| MH | 6 | 2 | 4 |
| Total | 38 | 15 | 23 |

Two female animals from each of the single-fed treatments (selected at random) were kept up to 32 kg liveweight and were then sacrificed and their empty body was chemically analysed.

*Slaughter procedure*. When a female pig reached the 32 kg liveweight, a provision for its slaughter was then made for the following day. On the day of slaughter the pig was weighed as usual and its weight was recorded as Final Liveweight (FLWT). Its feeding trough was removed and its feed intake was also recorded. At 9.30 am the animal was killed by an endocardiac injection of 5-10 ml Euthatal (RMB; containing 200 mg Pentobaribitone Sodium per ml) and it was transported immediately to the slaughter facilities, one mile distant.

The animal was re-weighed on a similar balance and the recorded weight called Dead Bodyweight (DBW). The difference between FLWT and DBW was considered to be due to a change in gut and bladder-fill. The pigs were then dissected into the minimum necessary components, to lessen blood losses. Of the internal organs only the spleen and liver were weighed. The stomach and intestines were removed and weighed full, stripped of their contents and then weighed empty. Gut-fill was then calculated by difference. A similar procedure was followed for the bladder, where the urine was emptied. However, this was necessary only for the male pigs, since females released their urine at death.

All organs, any collected blood and carcass, excluding gut-fill and urine, were placed in a doubled sealed plastic bag and stored at $-20^{o}C$.

*Chemical Analysis*. The whole carcass and non-carcass part of each pig had two passes through a Wolf-king mincer, fitted with a 10 mm and a 5 mm plate. An homogenous sample of 2000 g was then obtained from each pig. A 200 g sub-

sample, derived from the original sample, was then taken to the laboratory for chemical analysis.

Each sub-sample, which represented an individual animal, was analysed for:

(i) dry matter by freeze-drying to constant weight at -22°C.

(ii) nitrogen content of the dry matter by a macro-Kjehldahl procedure with crude protein calculated as 6.25 x nitrogen.

(iii) lipid content of the dry matter by Soxhlet extraction with 60-80°C petroleum ether for 8 hours.

(iv) ash content of the dry matter by burning in a muffle furnace at 600°C to constant weight.

(v) gross energy of the dry matter by adiabatic bomb calorimetry.

*Management*. The animals were weighed daily (during the morning) and fed twice a day (morning and afternoon) to minimise the spillage, which was low and measured. The weighing procedure started at 9.30 am and followed the same animal sequence every day. The feeding routine began immediately after weighing and also followed the same animal sequence. Feed refusals were weighed daily and discarded; for wet refusals the dry matter was measured. For the choice-fed animals, both troughs were removed at the same time, fresh feed was then placed in the troughs after weighing of the refusals, so as to offer each pig similar quantities of both feeds throughout the day.

The temperature aimed at for the major part of the experiment was 21-22°C. Therefore, once all the pigs had started consuming substantial amounts of creep feed, the temperature was lowered by 1-1.5°C per week. At the start of the experimental period the temperature was around 24°C.

### 2.8.4 Results

**(a) Single-fed pigs**

P1 The L pigs had a higher daily rate of feed intake, at a weight, than both M and H pigs, during the 12-30 kg liveweight interval (Figure 2.2). The average daily rate of feed intake at 1101 (s.e.46) g/d of the L pigs was significantly higher ($p<0.05$) than the rates of 948 (s.e. 24) and 876 (s.e. 27) g/d of the M and H pigs respectively. The average daily rates of intake of the M and H pigs were not significantly different ($p>0.1$).

C1 The average daily rates of feed intake were compared with the predictions of the Feed Intake Model. The model predicted that a given pig of a certain genotype (the genetic variables used were those estimated in Chapter I), of an average liveweight of 21 kg, will consume 1078, 969 and 963 g/d, when given *ad libitum* access to L, M and H feeds respectively. These predicted values were very similar to the observed rates of the L and M pigs, but significantly higher than the observed one for the H pigs ($p<0.05$). The systematic deviation (not always significant at a weight) of the actual rates of feed intake of pigs H from the predicted ones is also presented in Figure 2.3.

The feed intake model also predicted that none of the three feeds could provide the non-limiting conditions for the growth of these pigs in the environment used. Feed L with an inadequate level of CP, was predicted to cause the animals to grow protein at a slower rate than their potential, to show an increased rate of feed intake and excess lipid gain. Feeds M and H, though containing high levels of CP, were also predicted to be limiting at this house temperature. The pigs on these feeds would be able to achieve their potential-protein growth rate but their feed intake would be lower than their desired feed intake, and their rate of lipid gain less than the desired one.

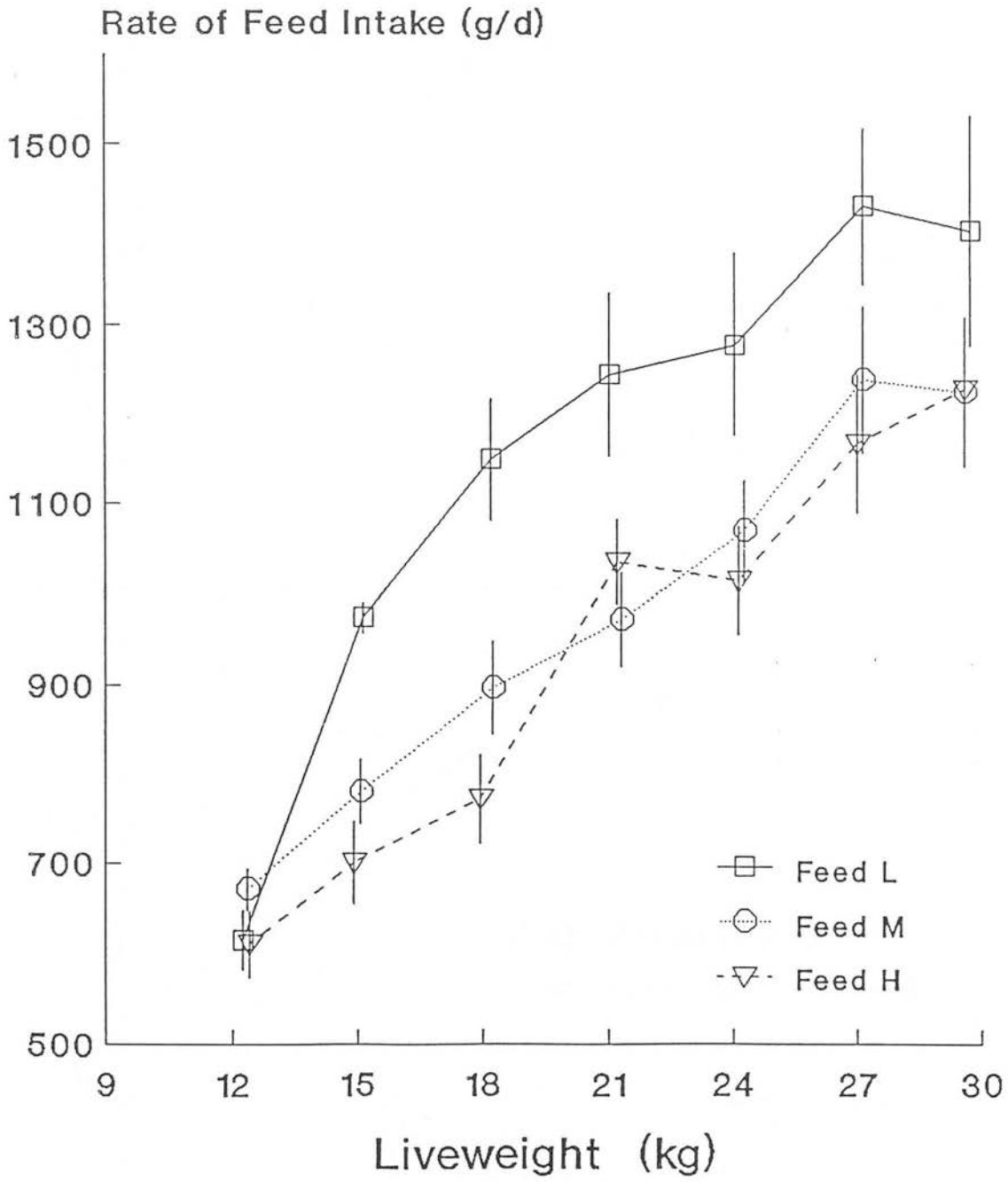


Figure 2.2. The rates of feed intake (g/d) of the single-fed pigs.

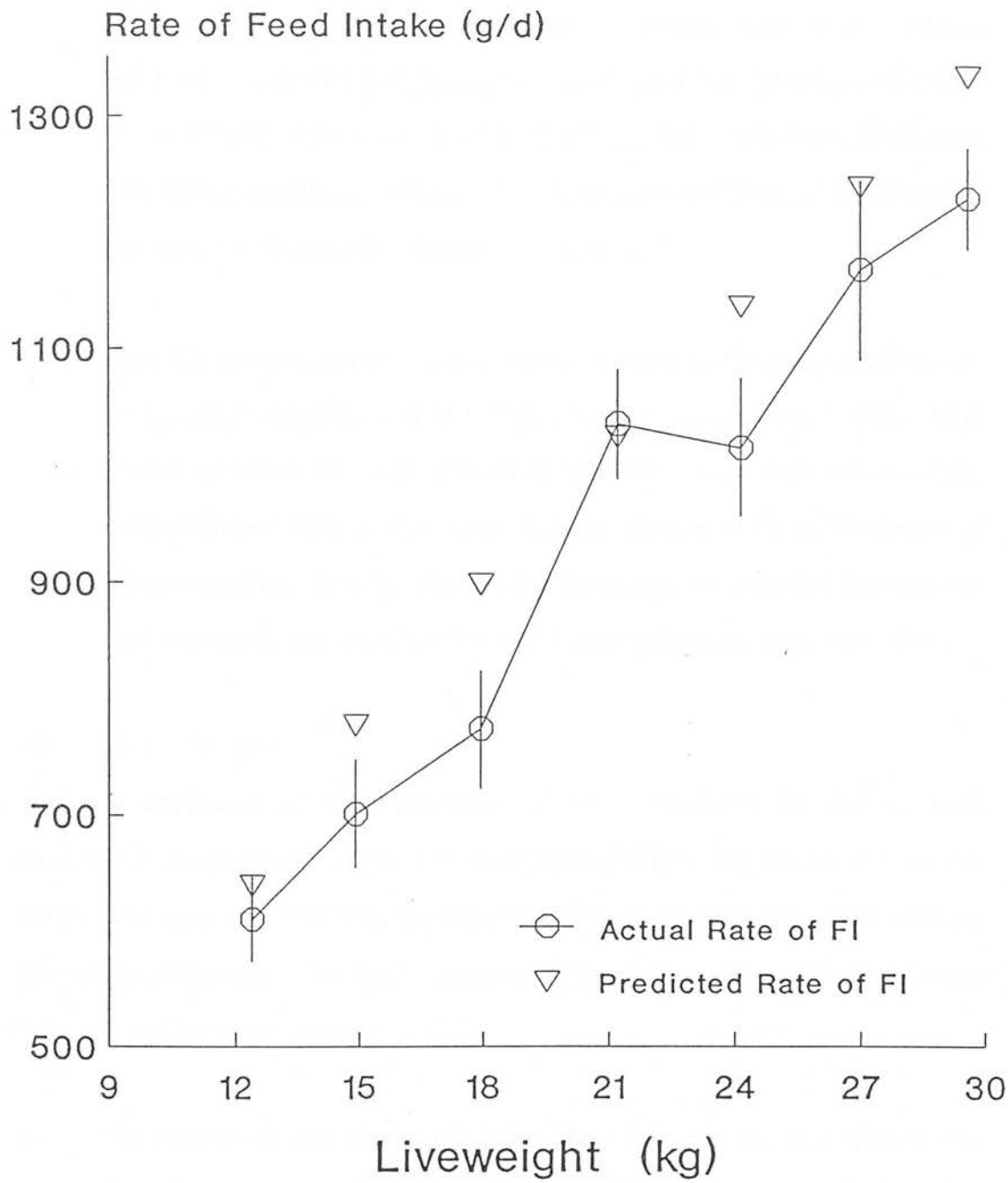


Figure 2.3 The predicted and actual rates of feed intake (g/d) of pigs given feed H only.

C2 The above predictions suggested that the description of the potential rate of liveweight gain in pigs, estimated in the form of the Gompertz function, could not apply for the analysis of this experiment. The observed growth rates and feed conversion efficiencies (FCE), which are presented in Table 2.6, support the suggestions of the model. The table shows that L animals had a slower rate of LWT gain and converted feed less efficiently than both M and H pigs, during the 12-30 kg LWT interval. Both these differences were highly significant ($p<0.01$). The daily gains and FCE of the M and H pigs were not statistically different to each other.

Table 2.7 summarises the effect of treatment (level of CP in the feed) on the empty body compositions of the single-fed pigs. L pigs had a higher lipid content than both M and H pigs, at 30 kg EBW. These pigs also contained less protein and water in their empty bodies. Because of the small number of animals sacrificed (two female pigs per treatment) no statistical comparisons were attempted, but the values for each individual pig are reported instead.

**(b) Choice-fed pigs**

A simple description of the composition of the diet selected by pigs on each treatment is the proportion of the total feed intake (TFI) which was taken from the trough containing the feed with the lower CP content in each pair, from now on referred to as prop. X. The treatment means of prop. X, together with the average CP protein selected, are given in Table 2.8.

P2 The expectation that pigs would select their diet in a directed manner was tested by comparing the proportion of the TFI which was taken from the trough containing the feed with the lower CP content in each pair against the null hypothesis prop. X = 500 g/kg TFI; that is a choice made at random. The proportion of feed L or M in the treatments LH and MH respectively

TABLE 2.6 **The effect of treatment (level of crude protein in the feed) on rate of feed intake, rate of liveweight gain and FCE of single-fed pigs, from 12-30 kg liveweight (mean (s.e.)).**

| | Treatment | | |
|---|---|---|---|
| | L | M | H |
| CP content | 131 | 225 | 332 |
| Feed Intake (g/d) | 1101 (42) | 948 (24) | 876 (27) |
| Gain (g/d) | 540 (27) | 718 (24) | 693 (13) |
| FCE (g gain/ g feed) | 0.490 (0.008) | 0.759 (0.026) | 0.793 (0.014) |

TABLE 2.7 **The empty body compositions (g/kg EBW) of the slaughtered single-fed female pigs at 30 kg EBW**

| | Treatment | | | | | |
|---|---|---|---|---|---|---|
| | L | | M | | H | |
| | 1 | 2 | 1 | 2 | 1 | 2 |
| LWT (g) | 31440 | 31260 | 31570 | 31860 | 31920 | 31400 |
| EBW (g) | 30011 | 29520 | 29993 | 30842 | 29961 | 30100 |
| Protein (g/kg) | 146 | 144 | 162 | 174 | 168 | 168 |
| Lipid (g/kg) | 231 | 211 | 164 | 110 | 101 | 128 |
| Water (g/kg) | 581 | 600 | 642 | 680 | 687 | 666 |
| Ash (g/kg) | 31 | 28 | 29 | 31 | 29 | 33 |
| Gross energy (MJ/kg) | 13.0 | 12.3 | 10.8 | 8.1 | 8.3 | 8.8 |

TABLE 2.8 The proportion of the Total Feed Intake (TFI) taken from the trough which contained the feed with the lower protein content (prop. X, g/kg TFI), and the CP selected (g/kg feed) in the diets of the choice-fed pigs

| Feed Pair | Prop X (s.e.) (g/kg TFI) | | | CP Selected (s.e.) (g/kg feed) |
|---|---|---|---|---|
| | Total | Period I (12-24 kg LWT) | Period II (24-30 kg LWT) | |
| L with M | 642 (116) | 655 (140) | 578 (126) | 164.7 (10.9) |
| L with H | 850 (023) | 861 (028) | 827 (026) | 161.2 ( 4.6) |
| M with H | 959 (014) | 978 (007) | 925 (031) | 229.4 ( 1.5) |

differed significantly ($p<0.001$) from prop. L or M = 500 g/kg TFI. However, the prop. L in the treatment LM was not different from random selection prop. L = 500 g/kg TFI, mainly due to considerable variation in the diets selected by individual pigs, and therefore P1 did not hold for this treatment.

P3 The data used for testing proposition (P3), that the pigs would not select their diet on the basis of the position of the feeds, were the prop. X values (where X is always the feed with the lower CP content in each pair) recorded for the day preceding the switching of the troughs at 24 kg LWT and the prop. X values for the day following the change.

The most obvious test for this proposition would be the comparison of the mean value for prop. X (after) and prop. X (before). However such a test would be ambiguous since each individual pig could fail to eat a similar prop. X (after) without affecting the mean prop. X for the group. In addition, since it was expected that the composition of the diet selection would change as the pigs matured (P5), such a change could also influence the significance of the test.

Consequently, the best test of the proposition was considered a visual appraisal of the data, presented graphically in Figure 2.4. In this graph the prop. X (day after) was plotted against the prop. X (day before). Points lying close to the solid line represent pigs whose diet selection was not affected by the change in the position of the feeds. Points lying close to the dotted line represent pigs which selected their diet on the basis of its position. It can then be seen that there is a considerable variation in the individual responses, with 10 out of 18 pigs following the feed.

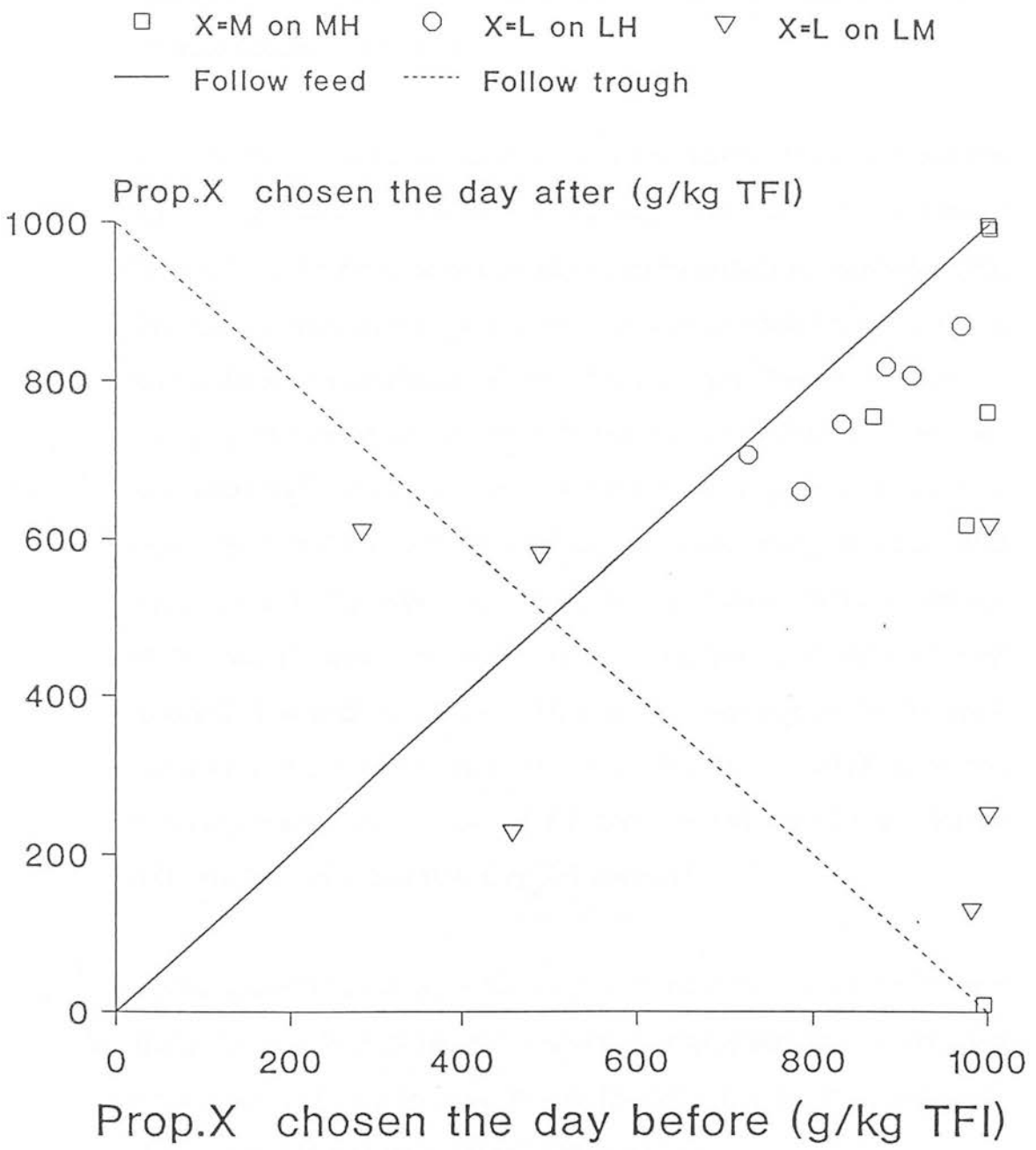


Figure 2.4 The effect of change in the position of the feeds on diet selection.

However, this variation was considerably reduced, when the prop. X was considered for the six days before and after the change (Figure 2.5). Then, only two animals appeared to select their diets on the basis of the feed position. Both these animals and the majority of the pigs which showed a preference for the feed position on the day following the change, belonged to the same treatment (pair LM).

P4 Since the idea that a pig minimises its excess of nutrient (protein) intake can only be tested when it is known, independently, exactly what the requirement for protein is, the design permitted only a limited analysis of proposition (P4). This could be made by the use of the data of treatment MH (where feed M is around the protein requirement of pigs of similar age). The data indicate that the prop. H selected was very low (41 (s.e. 14) g/kg TFI), which however was significantly different from the prop. H = 0 g/kg TFI (complete avoidance of feed H). An additional test was made, using the transformed (arcsine) data in this instance, due to the obvious skewness in the distribution of the prop. H value. Transformed prop. H was also significantly different ($p<0.001$) from prop. H = 0 g/kg TFI, suggesting that pigs on this treatment consumed some, however small amount of feed H. In addition, as was previously shown, prop. H was not 500 g/kg TFI and was also significantly different from prop. H = 1000 g/kg TFI ($p<0.001$).

Similar arguments could apply for the prop. H consumed by the pigs given a choice between feeds L and H. Animals on that treatment also consumed small amounts of feed H (prop. H was 150 (s.e. 23) g/kg TFI), which was significantly different from 500 and 1000 g/kg TFI.

P5 The method of formulation of the three feeds presented some problems in the formal test of the propositions (P5), that animals would select a diet of a

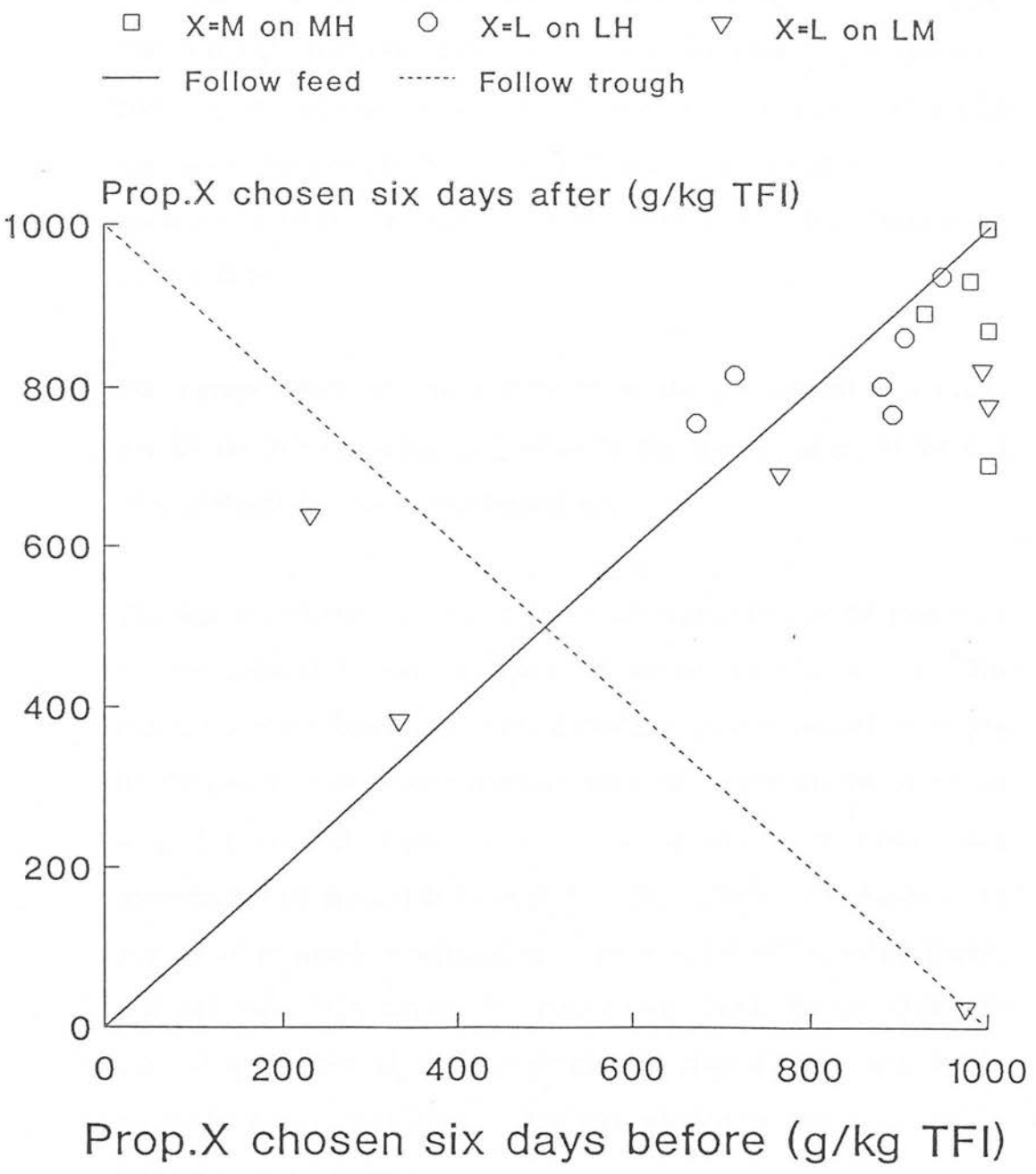


Figure 2.5 The effect of change in the position of the feeds on diet selection.

certain composition and consequently of a certain protein level. An analysis of variance on the treatment values reported in Table 2.8 suggested that there was a significant ($p<0.001$) effect of treatment on the CP level selected. This effect was due to the CP level selected by the pigs on treatment MH, since there was no difference between the CP selected between treatments LH and LM (although treatment LM was subjected to considerable variation). However, since pigs on pair MH did not have the opportunity to select a CP level lower than 225 g CP/kg feed (the CP content of feed M) the above test could not reject the proposition that pigs select a diet of a similar crude protein content.

P6 The average values for the composition of the diet selected at a weight provide the data for testing proposition P6 that the CP content of the diet selected would decrease as the pigs matured.

The data, graphically presented in Figure 2.6 suggest that the CP content of the diet selected in each treatment did not change with weight. The proportion of CP remained the same throughout the experimental period and the CP selected lines for each treatment were not significantly different from a straight line with a zero slope. From this analysis the points which represent the CP selected at 24 kg (CP selected following the change in the position of the troughs - indicated by an arrow on Figure 2.6) were excluded, and their values were replaced by missing ones. Again, the CP selected by the LM pigs varied between individuals and some of these pigs showed systematic changes with time. The diet selection of these pigs will be referred to in the discussion.

C1-C2 Since some of the asserted proportions (P3-P6) did not survive the test of this experiment, the corollaries (C1 and C2) could not apply for the results of the

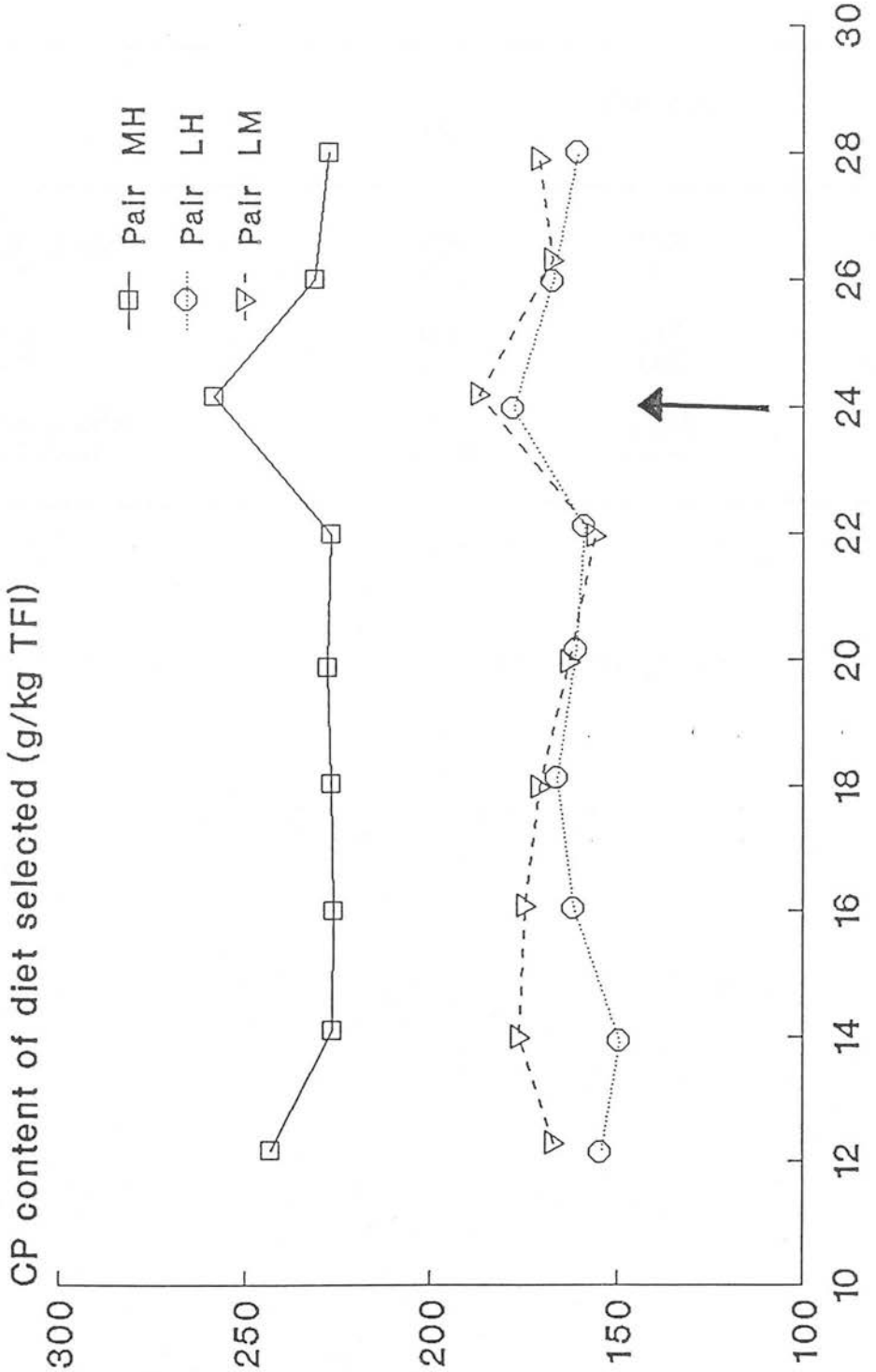


Figure 2.6 The average crude protein (CP) content, at a weight, of the diet selected by pigs on the three feed-pairs. The arrow indicates the change in the position of the troughs.

**TABLE 2.9** The average rate of feed intake, rate of liveweight gain and FCE of pigs given access to a pair of feeds, as a choice, from 12-30 kg liveweight (mean (s.e.)).

| | Treatment | | |
|---|---|---|---|
| | LM | LH | MH |
| Feed Intake (g/d) | 1030 (55) | 1057 (36) | 953 (30) |
| Gain (g/d) | 607 (10) | 614 (14) | 723 (20) |
| FCE (g gain/ g of feed) | 0.598 (0.035) | 0.589 (0.023) | 0.759 (0.013) |

experiment. Instead a tabular presentation of their daily rate of total feed intake, daily rate of LWT gain and FCE is given in Table 2.9.

The performance of the choice-fed pigs reflected their diets selected. Only the pigs on treatment MH achieved similar daily rates of feed intake and LWT gain to the single-fed pigs on either treatment M or H. The performance of the pigs on the treatments LM and LH was significantly worse (high rate of feed intake and slower growth rates) ($p<0.01$) than the above pigs.

### 2.8.5 An Intermediate Discussion of Experiment 1

It is often difficult to interpret the outcome of choice feeding experiments, where animals have failed to select a diet that supports their inherited growth plan. The obvious conclusion derived from the results of Experiment 1 would be that pigs given a choice between two feeds with different protein content, always prefer the feed with the lower protein content. Similar preference for a feed has often been referred to as 'a liking for the taste of a feed' and the term 'palatability' has often been used in order to explain the outcome of choice feeding experiments (eg. Goacher and Church, 1970; Kennedy and Baldwin 1972; Grovum and Chapman, 1988). However, 'palatability', or better, 'relative palatability' is usually a redundant notion since it is invoked simply because the animal is observed to eat more of one feed than another. Since a transient external scale for the 'relative palatability' has yet to be constructed, the term is better discarded when dealing with animals, to be replaced with simple quantitative statements of the two feeds concerned.

Wallace, Houser and Combs (1966) offered pigs a choice between five feeds with different copper contents. The pigs always preferred the feed with the lower copper content and consequently selected a diet with a copper content much lower than their presumed requirements. Braude (1967) in interpreting their results suggested that

animals were doing so in a form of nutritional economy. His suggestion could then account for the results of Experiment 1, but also would imply that pigs do not have the desire to fulfil their growth plan in the shortest period of time, which is contrary to what has been proposed so far. Therefore, it would be more useful to view the results in the framework of the theory which has been described so far, and to use the apparent contradictory outcomes to define more clearly the nature of choice feeding behaviour and the conditions which constitute a free choice of feeds.

It was previously suggested that the majority of the experiments which show the failure of animals to select non-limiting diets could be seen as belonging to the class of experiments which did not give the animals the necessary choice to choose from. Experiment 1 one will be considered as belonging to this type of experiment and some reasons for this are discussed below:

(i) The predictions of the Feed Intake Model implied that pigs on M or H feeds could not achieve their desired lipid gain (at least for some part of the experiment). Thus, when feeds L, M and H were offered as two way choices, the pig's decision for its diet selection was more difficult than was intended. For example, a choice between L and H was a choice between a feed limiting for growth (L) and a feed limiting for the desired lipid retention (H); in fact a limiting/limiting choice.

Although some choices would be easier to make, if it is assumed that in complicated choices animals select their diets according to the priorities for growth (Chesters and Quarterman, 1970), it will still be expected that there would be considerable confusion and hence variation in the diets selected by individuals. This suggestion could be substantiated by the behaviour of the pigs on the LM treatment. The CP selected at a weight by each individual on this treatment varied considerably and for some pigs showed systematic

changes with time. Examples are shown in Figure 2.7. However, it cannot account for the behaviour of the ML or LH pigs, which neither varied much among individuals nor were their diets selected according to their priorities for growth.

(ii) When feed H was offered singly to pigs, a considerable depression of feed intake was observed throughout the experimental period. It was previously discussed that a feed can be considered as toxic when it causes a depression in the rate of feed intake. When a toxic feed is offered as a choice, together with a non-toxic feed, then the animal will avoid the former feed to a major extent. The term 'toxic' is used here in its broader sense and it can refer to:

(a) the quality of the protein that the feed supplies, ie. the relative contribution of different amino acids (Leung *et al*, 1968; Musten *et al*, 1974).

(b) nutritional properties of the ingredients other than protein (eg. digestibility, fat content, minerals) (Pamp *et al*, 1977).

(c) non-nutritional properties (eg. glucosinolates or tanins in the raw materials).

Similarly, if feed H was offered as a choice, with either M or L, and was avoided, and the avoidance was consistent across pigs, then it could also be considered as 'toxic'.

From the ingredients and the method of formulation of feed H, only pruteen could be suspected as belonging to one of the above classifications of toxicity. Pruteen, as the product of a microbial protein, contains high levels of nucleic acids (D'Mello, Peers and Whittemore, 1976). The ingested nucleic acids are excreted as uric acid and allantoin in the urine, and this conversion represents 75 per cent of the

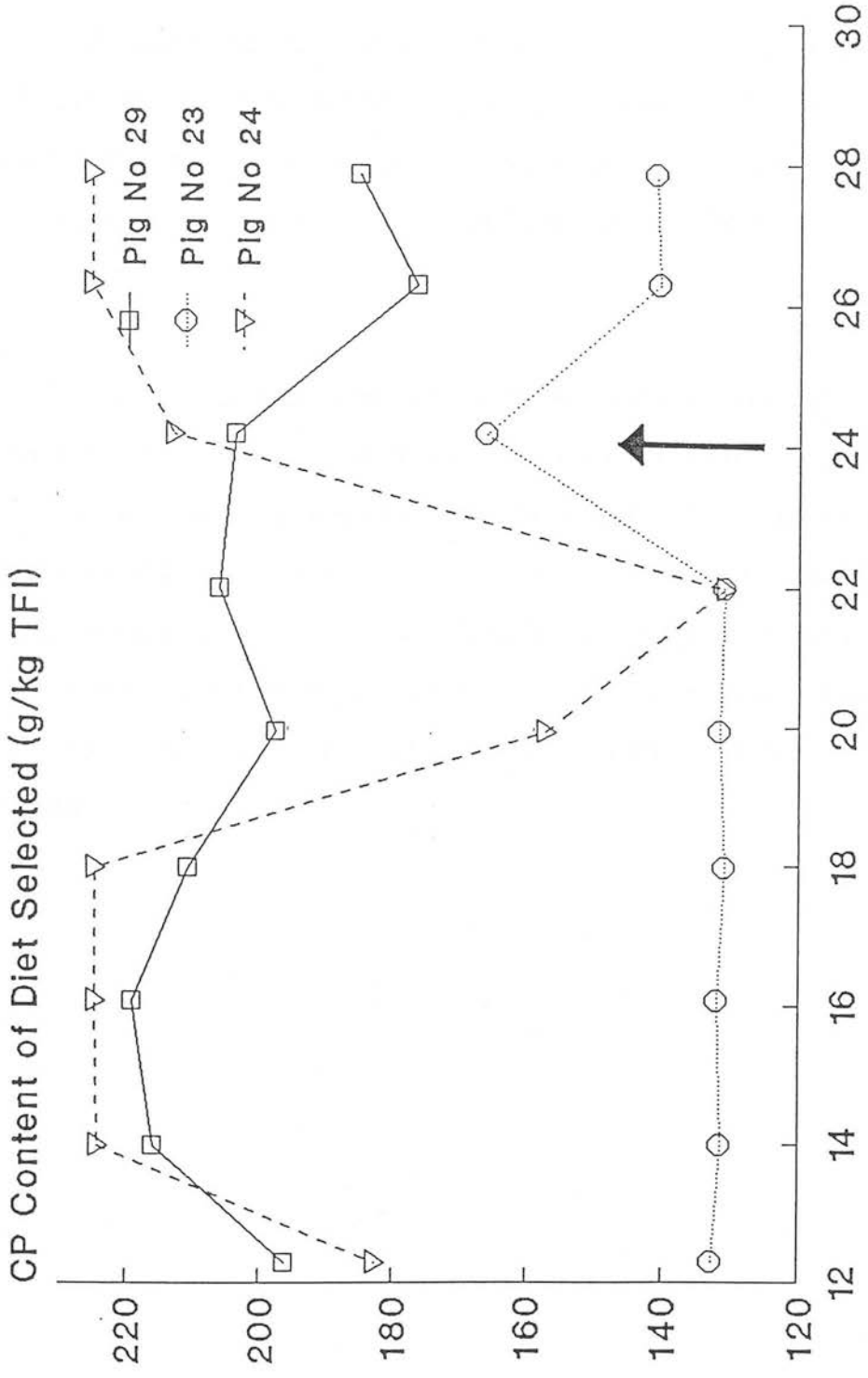


Figure 2.7 The crude protein (CP) content, at a weight, of the diets selected by individual pigs on treatment LM. The arrow indicates the change in the position of the troughs.

conversion of nucleic acids to allantoin and indicates that little, if any, salvage of nucleic acids occurs (Newport and Keal, 1980). If there is a limit to the amount of nucleic acids that can be converted and excreted by the animal, then the high levels of inclusion of pruteen in the feed could cause accumulation of nucleic acids in the body. This could result in a depression of feed intake until the nucleic acids are catabolised and excreted. The above hypothesis is supported by the fact that the manufacturing company of pruteen recommends only 10-14 per cent levels of inclusion of pruteen for young pigs, in order to obtain optimum growth and FCE (ICI, 1981).

At this stage, it was decided to test the above hypothesis which, if true, would effectively mean that pigs in Experiment 1 were not given the necessary choice to choose from, since feed H was toxic. This test would imply the use of feeds with protein sources other than pruteen, as well as pruteen-based feeds, offered in a two-way choice situation. Animals given a choice between a low and a high protein feed (none of them containing pruteen) would be expected to choose a diet which meets their requirement for protein and consequently grow at a rate set by their inheritance.

## 2.9 EXPERIMENT 2 : A SECOND TEST OF THE THEORY OF DIET SELECTION

### 2.9.1 Objectives

The experiment was undertaken to test the idea that a feed with a high level of inclusion of pruteen is 'toxic' for growing pigs. When such a feed is given alone to pigs, it is expected to cause a depression in feed intake. When it is offered as a choice, it will be avoided. As a consequence of this avoidance, the pigs may fail to select a diet which is adequate to support their potential growth.

It has been assumed that when an animal is given a choice between two feeds which differ widely in their protein:energy ratio and meet the necessary conditions for bulkiness and toxicity, it will be able to select a diet that meets its requirements. A part of this experiment was designed to test the theory of diet selection; a theory which carried an implicit definition of the non-limiting conditions required by the pigs to fulfil their inherited growth plan.

In order to test the above two ideas, pigs were given free and continuous access to a pair of feeds which differed in their protein:energy ratio and in the sources from which the protein came.

### 2.9.2 Material and Methods

*Animals*. Forty Cotswold Large White x Landrace pigs (20 entire males and 20 entire females) from 5 litters, were individually caged in the controlled environment portacabin. The animals were moved immediately after weaning (at 4 weeks of age) and had not had any previous experience on creep feed.

*Feeds*. The tests required feeds with different protein levels, and feeds with similar protein yields derived from different protein sources. Therefore, five feeds with three different CP levels (a low (L), two medium ($M_P$ and $M_F$) and two high ($H_P$ and $H_F$)), but with similar energy yields were formulated and made into pellets

(Table 2.10). The low protein feed (L) was similar to the low protein feed used in Experiment 1 and was formulated to be inadequate in crude protein to support potential growth, when offered *ad libitum*. The two major ingredients used for the formulation of this feed were oatflakes and milk replacer. The high protein feeds ($H_P$ and $H_F$), intended to be abundant in CP, were made by substituting either herring meal and milk replacer (feed $H_F$) or pruteen and milk replacer (feed $H_P$) for the oatflakes of feed L. The medium feeds ($M_P$ and $M_F$) were 0.5 L + 0.5 $H_P$, and 0.5 L + 0.5 $H_F$ respectively. All five feeds were intended to be non-limiting in minerals and vitamins. The chemical analyses of the feeds are shown in Table 2.11.

Feed $M_P$ contained 150 kg pruteen/tn, which is around the recommended level of inclusion in feeds for growing pigs (ICI, 1981). However, feed $H_P$ contained 300 kg pruteen/tn, in order to reveal any toxic effects of the feed on growing pigs. Pruteen and fishmeal have been reported to have a similar essential amino acid composition and similar values for net protein utilisation and biological value (BV) (D'Mello *et al*, 1976; Braude, Mitchel and Rhodes, 1975), a factor which facilitates the comparisons between the feeds with similar CP content. In addition, fishmeal was assumed not to contain any factors which could be considered as toxic and cause a depression in the feed intake of pigs.

*Experimental Design*. A complete two-way choice feeding experiment, using five feeds has fifteen treatments, viz, the five feeds fed singly as controls and the ten combinations of the five feeds given as two-way choices. Unfortunately, the experimental resources available were limited to 40 cages, of which 20 were converted to accommodate two troughs. Hence, it was only possible to include those treatments considered essential for testing the propositions of this experiment. The five choice feeding treatments chosen were:

TABLE 2.10 The composition of the five feeds (kg/tn fresh weight) used in Experiment 2.

| Ingredients (kg/tn) | FEED | | | | |
|---|---|---|---|---|---|
| | L | $M_P$ | $M_F$ | $H_P$ | $H_F$ |
| Pruteen | - | 150 | - | 300 | - |
| Herring meal | - | - | 150 | - | 300 |
| Oatflakes | 727 | 482 | 481 | 210.5 | 207.5 |
| Milk replacer | 185 | 296 | 296 | 410 | 410 |
| Molasses | 50 | 50 | 50 | 50 | 50 |
| PT10C Vitamin and Mineral supplement[a] | 5 | 5 | 5 | 5 | 5 |
| Vitamin E supplement | 7.5 | 8.5 | 9.5 | 11 | 11 |
| Salt | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Dicalcium Phosphate | 23 | 6 | 6 | 11 | 14 |
| | 1000 | 1000 | 1000 | 1000 | 1000 |

[a] See Table 2.3

TABLE 2.11 The chemical analysis of the five feeds (g/kg fresh weight) used in Experiment 2

| Component (g/kg) | FEED | | | | |
|---|---|---|---|---|---|
| | L | $M_P$ | $M_F$ | $H_P$ | $H_F$ |
| Digestible energy[a] (MJ/kg) | 15.8 | 16.4 | 16.1 | 17.3 | 16.5 |
| Dry Matter | 912 | 920 | 920 | 929 | 927 |
| Crude Protein (CP) | 126 | 223 | 226 | 325 | 319 |
| Ether Extract | 95 | 103 | 100 | 96 | 91 |
| Ash | 60 | 63 | 69 | 84 | 90 |
| Crude fibre | 20 | 15 | 13 | 9 | 8 |
| Gross energy (MJ/kg) | 17.2 | 18.2 | 18.1 | 18.5 | 18.3 |

a values calculated from feed tables

(a) Treatment $H_PH_F$ to test the proposition that growing pigs strongly avoid feeds with high levels of inclusion of pruteen. This proposition could be also tested by treatment $M_PH_F$, but not as severely as by $H_PH_F$, because of the lower level of inclusion of pruteen in feed $M_P$.

(b) Treatments $LH_F$ and $LH_P$ to test the proposition that pigs are able to select a diet that could support their potential growth, only when the two feeds meet the necessary conditions for toxicity.

(c) Treatments $M_PH_F$ and $M_FH_P$ to test the proposition that pigs avoid an excess of protein intake only when the two feeds differ in one nutritional variable (protein:energy ratio in the feed).

The number of the remaining cages could accommodate all the single-feeding treatments (L, $M_P$, $M_F$, $H_P$ and $M_F$). The animals were randomly allocated to the treatments, taking account of age at 12 kg liveweight and with restriction for litter origin. Each treatment had two animals of each sex. The position of the feeds did not change throughout the experiment, but their position was randomised across pigs. The experiment ended when animals reached 30 kg liveweight; at this stage all single-fed animals were sacrificed and their empty bodies were chemically analysed.

*Slaughter schedule and chemical analysis*. The slaughter procedures and chemical analyses were similar to those described in Experiment 1. When a pig reached 30 kg liveweight provision for its slaughter was then made for the following day. On the day of slaughter, the pig was weighed as usual, its feeding trough was removed and its feed intake was also recorded. At 8.30 am the animal was killed and it was transported immediately to the slaughtering facilities.

*Management*. The animals were weighed daily and fed twice a day. The weighing procedure started at 9.30 am and followed the same animal sequence every day. The feeding routine began immediately after weighing and also followed the same animal

sequence. Feed refusals were weighed daily and discarded; for wet refusals the dry matter was measured. The temperature intended for the major part of the experiment was 21-22$^{o}$C. However, a hot spell, which lasted from the 14th to the 20th of July 1987, resulted in house temperatures of 25-26$^{o}$C, especially during the daytime. The effects of this increase in temperature on the feed intake of the animals are carefully considered in the Results section of this experiment.

### 2.9.3 Propositions

(a) **Single-fed pigs**

P1A Pigs will increase their rate of feed intake, at a weight, as the protein content of the feed is decreased. This proposition will only apply for the pigs on the fishmeal based feeds.

P2A Pigs on pruteen-containing feeds will have a depressed rate of feed intake, when compared with pigs on fishmeal based feeds, at the same level of crude protein.

(b) **Choice-fed pigs**

(a) Pigs given a choice between a pair of feeds, neither of which contains pruteen (ie. pair $LH_F$):

P1B will choose between the two feeds on offer in a directed, non-random manner.

P2B will select a diet of a certain composition, according to the protein content of the feeds on offer, at a given degree of maturity.

P3B The protein content of the diet selected will decrease as the pigs mature.

(b) Pigs given a choice between a pair of feeds, one of which contains high levels of pruteen:

P4B will choose between the two feeds on offer in a directed, non-random manner in order to avoid the pruteen containing feed.

P5B will fail to minimise the excess of nutrient (protein) intake in order to avoid the pruteen containing feed.

### 2.9.3.1 Corollaries

(a) **Single-fed pigs**

C1A The rate of the increase of feed intake, the growth rate and the body composition at 30 kg liveweight will follow the prediction of the Feed Intake Model (this corollary will not apply for the pigs on pruteen-based feeds).

C2A Pigs on a high nutrient:energy fishmeal containing feed and not limited by the environment (ie. house temperature) will grow at a rate set by their inheritance.

(b) **Choice-fed pigs**

Should all propositions P1B-P5B survive, the following corollaries apply:

C1B Only the pigs given a choice between a limiting feed (L) and an abundant feed containing fishmeal ($H_F$) will have a daily rate of total feed intake which will be dependent on their energy requirement and that predicted by the Feed Intake Model.

C2B The above pigs, given the opportunity, will grow at a rate set by their inheritance.

### 2.9.4 RESULTS

(a) **Single-fed pigs**

The unexpected increase in ambient temperature, which lasted for five days, imposed an additional difficulty to the way that the results could be analysed and compared. The animals were at different stages of growing when this increase occurred, with

some pigs still being in the pre-experimental period. Therefore, the best way of presenting such results would be separate graphs of the daily feed intake and growth curves for each pig. This method of presentation would then permit a comparison of the rate of feed intake for each pig with the predictions of the Feed Intake Model, taking account of any changes in the house temperature.

Unfortunately, this method is beyond the scope of this thesis and instead, the conventional way of presenting the results from the single-fed pigs in a tabular form, was used. Two pigs had to be excluded from the analysis, as atypical due to ill health: (i) a female pig on feed L, which showed extremely low feed intakes and slow daily gains, compared with the other pigs on the same treatment; the post-mortem examination revealed the existence of sub-clinical pneumonia; (ii) a male pig on $M_P$, which developed a severe scouring at 24 kg liveweight.

(i) *Effect of temperature on feed intake*. There was a significant decrease in the daily rate of feed intake of all pigs when the house temperature was increased from 23°C to 25-26°C. This effect can be seen in Figure 2.8, where the daily rates of feed intake of pigs on $H_P$ and $H_F$ were plotted against time (calendar days). Each point on the figure represents the average of three pigs per treatment, since one animal from each treatment was at that time still in the pre-experimental period. The decrease, from 804 to 528 g/d and from 705 to 421 g/d for treatments $H_P$ and $H_F$ respectively, agreed qualitatively with the predictions of the model. The model predicted that a similar change in the temperature (of 2°C) would result in a decrease in the daily rate, of a pig weighing 24 kg, of 215 g/d.

(ii) P1A-P2A

As expected (P1A), the average rate of feed intake during the 12-30 kg liveweight interval, increased as the protein level of the feed was decreased


Figure 2.8 The effect of an increase in the house temperature (dotted line) on the rate of feed intake of single-fed pigs (treatments $H_F$ and $H_p$).

(Table 2.12); the increase was highly significant ($p<0.01$). All the means of the average rates of feed intakes were subjected to a considerable variation, due to the different effects of the increase in the house temperature on the rates of feed intakes of individual pigs.

The protein source did not affect the rate of feed intake and therefore pigs on the same level of protein had similar feed intakes (feed $M_F$ vs feed $M_P$ and feed $H_F$ vs feed $H_P$; Table 2.12). The rate of feed intake on the L, $M_F$ and $M_P$ feeds agreed with the values predicted by the Feed Intake Model, but it deviated systematically from the predictions of the rates of intake on the high protein feeds ($H_F$ and $H_P$). Therefore, the proposition (P2A), that animals on a feed with high levels of inclusion of pruteen would have a reduced rate of feed intake when compared with animals on the fishmeal based feeds, had to be rejected.

(iii) C1A-C2A

The model predicted that at high temperatures, none of the five feeds could provide the non-limiting conditions for the growth of these pigs. Feed L contained inadequate levels of CP, and therefore the animals were predicted to grow protein at a slower, and lipid at a faster rate. Medium protein feeds ($M_F$ and $M_P$) and high protein feeds ($H_F$ and $H_P$) were also limiting in this environment, mainly because the pigs could not achieve their desired level of fatness at the temperatures used. Any increase in the house temperature was more likely to affect the lipid gains of the animals on the high protein feeds. Therefore the gain of the animals on these feeds ($H_F$ and $H_P$) was expected to have more protein and less fat when they were compared with the medium protein feeds.

TABLE 2.12 **The effect of treatment (level of crude protein in the feed) on rate of feed intake, rate of liveweight gain and FCE of single-fed pigs, from 12-30 kg liveweight (mean (s.e.)).**

| | Treatment | | | | |
|---|---|---|---|---|---|
| | L | $M_P$ | $M_F$ | $H_P$ | $H_F$ |
| CP content (g/kg fresh feed) | 124 | 219 | 223 | 320 | 314 |
| Gain (g/d) | 512 (60) | 686 (56) | 693 (14) | 546 (37) | 585 (39) |
| Feed Intake (g/d) | 1043 (115) | 925 (79) | 891 (28) | 739 (27) | 743 (29) |
| FCE (g of gain/ g of feed) | 0.490 (0.006) | 0.743 (0.018) | 0.780 (0.024) | 0.739 (0.034) | 0.788 (0.038) |

The above predictions suggested that the description of the potential rate of liveweight gain in pigs estimated in the form of the Gompertz function could not apply for the analysis of this experiment. However, the observed growth rates and FCE (Table 2.12) supported the suggestions of the model. Animals on the medium protein feeds had significantly higher growth rates ($p<0.05$) than pigs on the high protein feeds. When the growth rates of this experiment were compared with the results of Experiment 1, it was found that all animals in Experiment 2 grew at a slower rate than those on feeds with similar CP levels in Experiment 1. For example, pigs on feed H in Experiment 1 grew significantly faster ($p<0.05$) (at 693 g/d) than pigs on $H_P$ and $H_F$ in Experiment 2 (585 and 546 g/d, respectively).

Table 2.13 summarises the effect of treatment (level of CP in the feed) on the empty body compositions of the single-fed pigs at 30 kg liveweight. As was expected (C1A), there was a significant effect of treatment on the protein and lipid content of the empty bodies of pigs. The relationship between the body protein content at 30 kg liveweight and the level of CP in the feed was essentially linear ($p<0.001$) and there was no significant effect of sex on empty body protein content. This finding supported the suggestion that pigs on the high protein feeds had a higher amount of protein in their gain (protein gain that of their potential) than pigs on the medium protein one. The relationship between the lipid content of the empty body and the CP level of the feed was both linear ($p<0.001$) and quadratic ($p<0.001$) with L pigs being 2.4 times fatter than pigs on $H_P$ or $H_F$ feeds. Finally, there was a highly significant effect of sex ($p<0.001$) on the lipid content, with female pigs being consistently fatter than male pigs in all treatments (144 vs 116 g lipid/kg EBW respectively). All the interactions were inappreciable and not significant.

(b) **Choice-fed pigs**

P1B-P3B The usual test for the proposition (P1B) that the diet was selected in a directed manner, is to compare the prop. L (which is the proportion of the

TABLE 2.13 The effect of treatment (level of crude protein in the feed) on the empty body composition (g/kg EBW) of pigs at 29 kg EBW (n = 4), (mean (s.e.))

| | Treatment | | | | |
|---|---|---|---|---|---|
| | L | $M_P$ | $M_F$ | $H_P$ | $H_F$ |
| LWT (g) | 29977 (132) | 30740 (554) | 30715 (601) | 30110 (184) | 30010 (152) |
| EBW (g) | 28550 (110) | 29218 (415) | 29189 (721) | 28845 (284) | 28653 (243) |
| Protein (g/kg) | 150 (3) | 165 (5) | 167 (2) | 178 (1) | 174 (4) |
| Lipid (g/kg) | 217 (10) | 131 (4) | 121 (9) | 86 (13) | 95 (14) |
| Water (g/kg) | 597 (9) | 663 (12) | 663 (9) | 688 (12) | 689 (13) |
| Ash (g/kg) | 31 (3) | 33 (2) | 36 (3) | 34 (1) | 32 (1) |
| Gross Energy (MJ/kg) | 11.8 (0.4) | 9.0 (0.5) | 8.9 (0.3) | 7.8 (0.5) | 7.9 (0.5) |

TFI which was taken from the trough containing feed L, in pair $LH_F$) against the hypothesis prop. L = 500 g/kg TFI, that is a choice made at random. However, this test could not be useful in this case, since from the setup of the experiment pigs were expected to choose a diet close to 50-50 per cent, if they were to meet their requirement. Therefore, although prop L = 774 (s.e. 132) g/kg TFI was not significantly different from the null hypothesis, this could not be used to reject the proposition.

Instead, the path of diet selection was decided to be traced by first calculating the difference in the cumulative feed intake of one feed (X) and the cumulative feed intake of the other feed (Y), giving Cumulative Difference (X-Y). These values were plotted against the Cumulative Total Feed Intake (X+Y). The graph of these values, which are orthogonal (Figure 2.9) permits the following, more pertinent aspects of the diet selection to be surveyed at a glance:

(i) the trend in the diet selection (Cumulative Difference XY) is directly related to total feed intake (Cumulative Total XY).

(ii) an animal which makes a dietary choice exclusively in favour of one of the feeds traces a path [Cumulative Difference XY = Cumulative Total XY or Cumulative Difference XY = - (Cumulative Total XY)]

(iii) the angle of the plotted path reflects the relative proportion of the two feeds in the diet selected (ie. when Cumulative Difference XY = 0, then prop. X = 500 g/kg TFI).

(iv) freak, short-term changes in the diet composition, disruptive to other plotting techniques (eg. prop. X against time), are smoothed out and the progress of an individual can be traced as it moves through all the possible combinations of the feeds on its way to the mature diet composition.

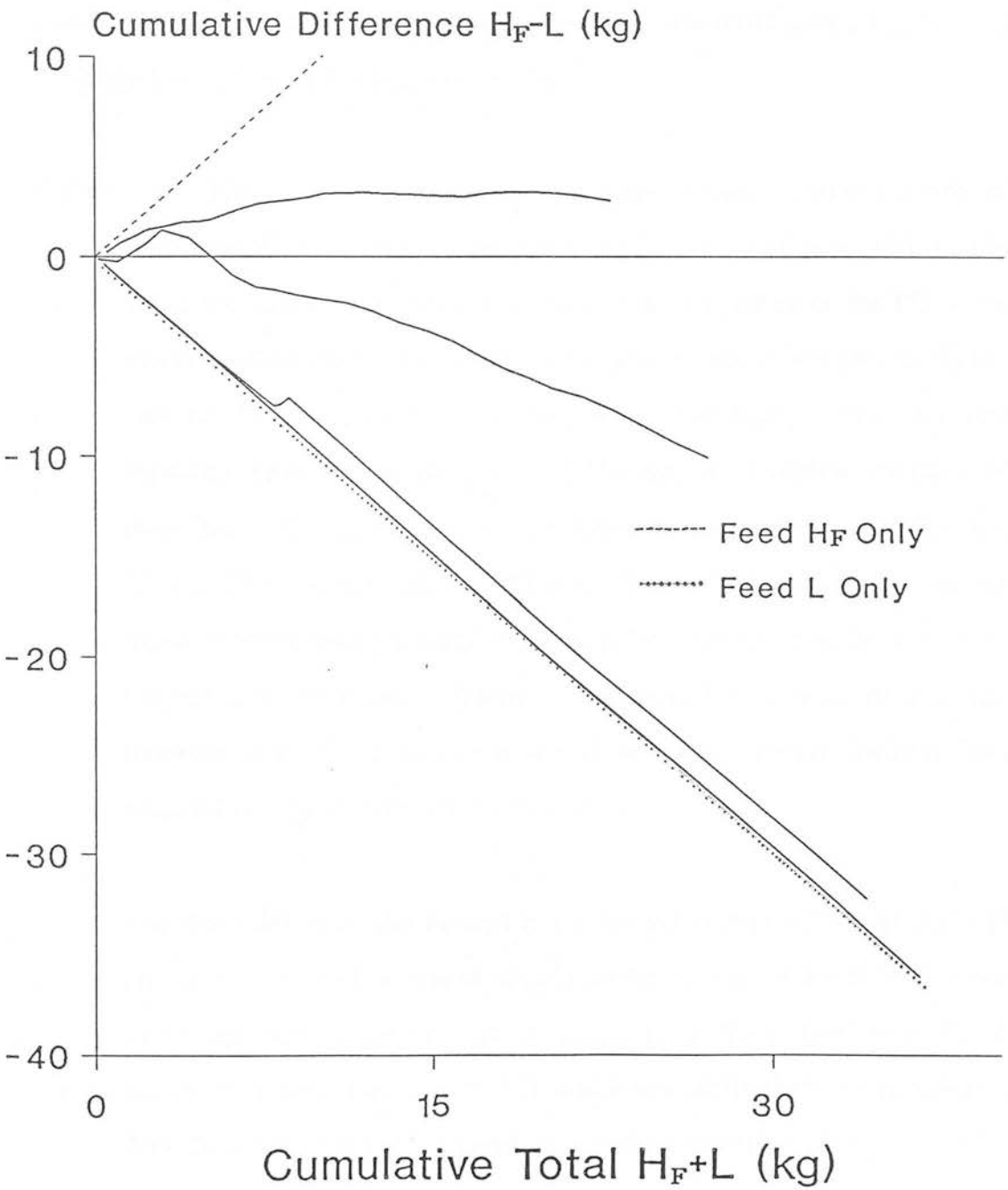


Figure 2.9 The paths of diet selection in growing pigs given a choice between feeds L and $H_F$. Each line refers to an individual pig.

When the graphs for each individual pig offered a choice between L and $H_F$ feeds were plotted in this way (Figure 2.9), it can be seen that their path of diet selection varied considerably. Two pigs showed a complete preference for feed L, one pig selected a diet of prop. L = 686 g/kg TFI and only one pig selected a diet, where its protein content declined over time. For this latter pig, the initial preference for feed H changed to a 50-50 per cent diet composition.

P4B-P5B The expectation (P4B) that pigs given a choice between a pair of feeds, one of which contains high levels of pruteen, would select their diet in a directed manner, was tested by comparing the proportion of the TFI which was taken from the trough containing the pruteen-based feed ($M_P$ or $H_P$) in each of the four pairs $LM_P$, $M_PH_F$, $M_FH_P$ and $H_PH_F$, against the null hypothesis prop. ($M_P$ or $H_P$) = 0 g/kg TFI, that is a complete avoidance of these feeds. The prop. $M_P$ or $H_P$ selected in the four pairs was 418 (s.e. 76), 726 (s.e. 200), 770 (s.e. 220) and 387 (s.e. 190) g/kg TFI respectively, and was found to be significantly ($p<0.05$) different from the null hypothesis only for the first three treatments. However, when prop. ($M_P$ or $H_P$) was angularly transformed it was found that it was significantly different ($p<0.05$) from prop. ($M_P$ or $H_P$) = 0, for all the four pairs.

The above test could also be used to test the proposition (P5B) that pigs will fail to minimise their excess of protein intake in order to avoid the pruteen containing feed. Since the null hypothesis prop. $H_F$ = 1000 g/kg TFI is equivalent to prop. $M_P$ = 0 g/kg TFI, which was earlier shown to be different from the results, the above proposition had also to be rejected.

Finally, a considerable variation was also observed in the paths of diet selection of individual pigs in each of the four treatments (Figures 2.10, 2.11, 2.12, 2.13). For example, it can be seen in Figures 2.11 and 2.12 that three

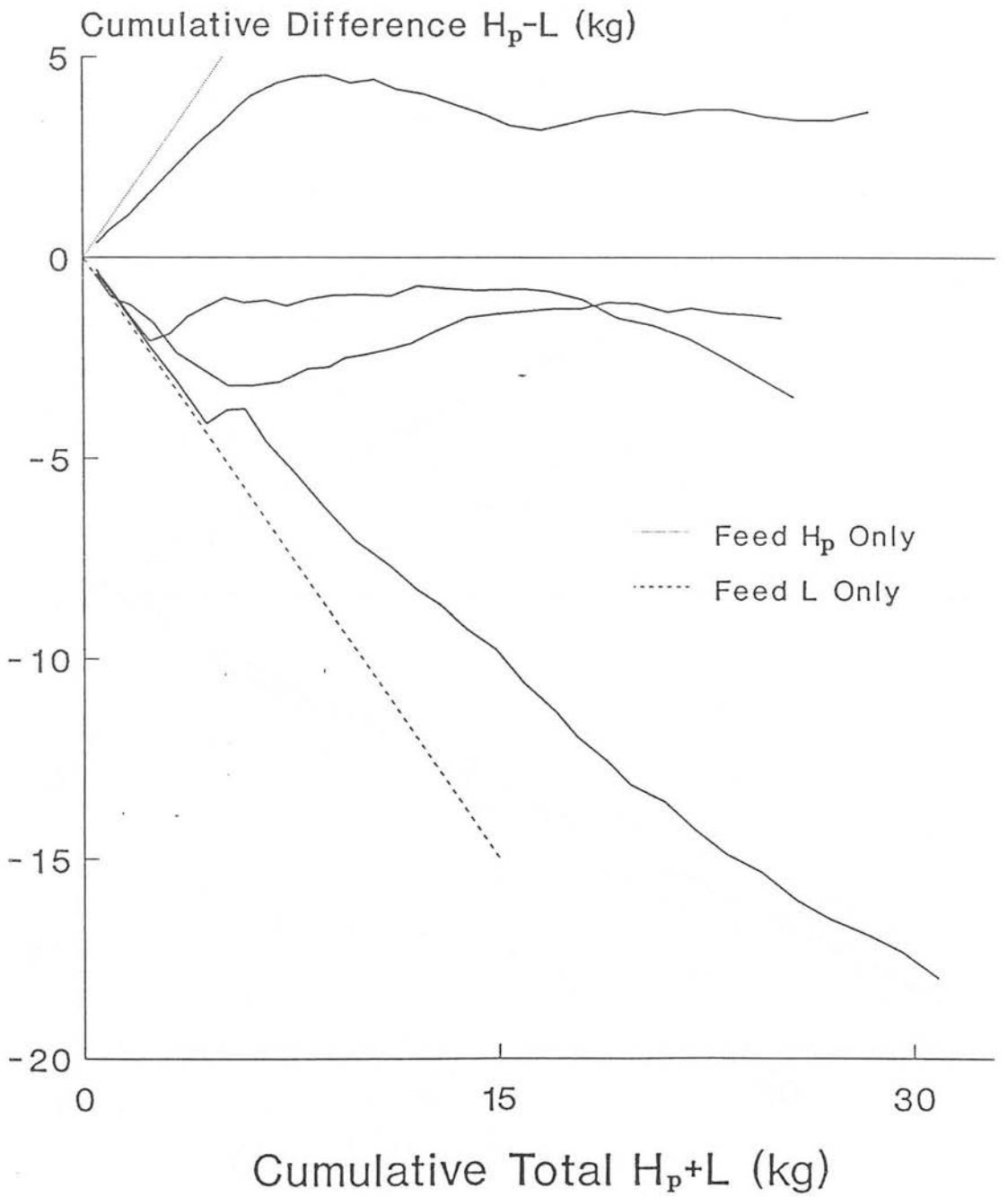


Figure 2.10 The paths of diet selection in growing pigs given a choice between feeds L and $H_p$. Each line refers to an individual pig.

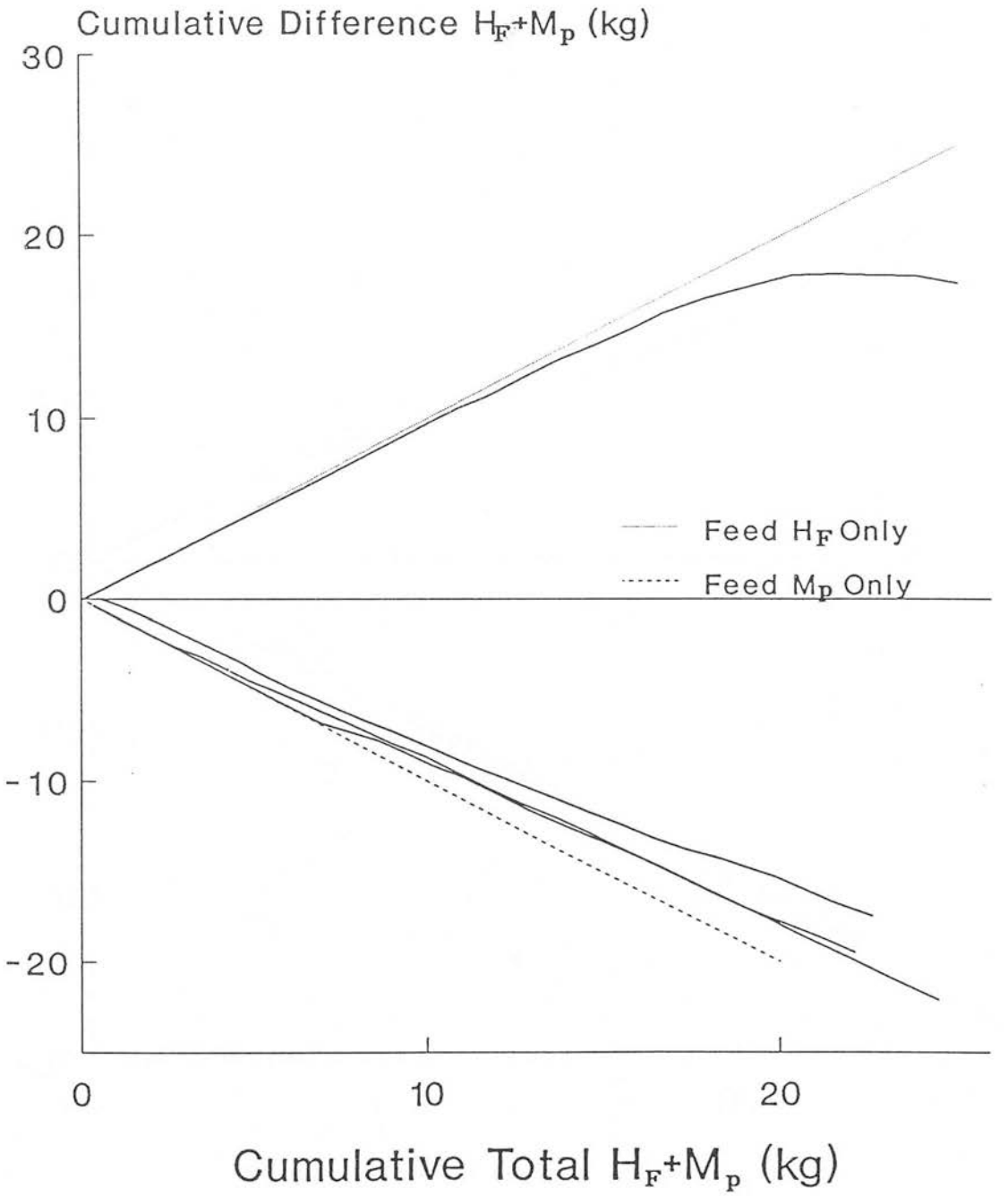


Figure 2.11 The paths of diet selection in growing pigs given a choice between feeds $M_p$ and $H_F$. Each line refers to an individual pig.

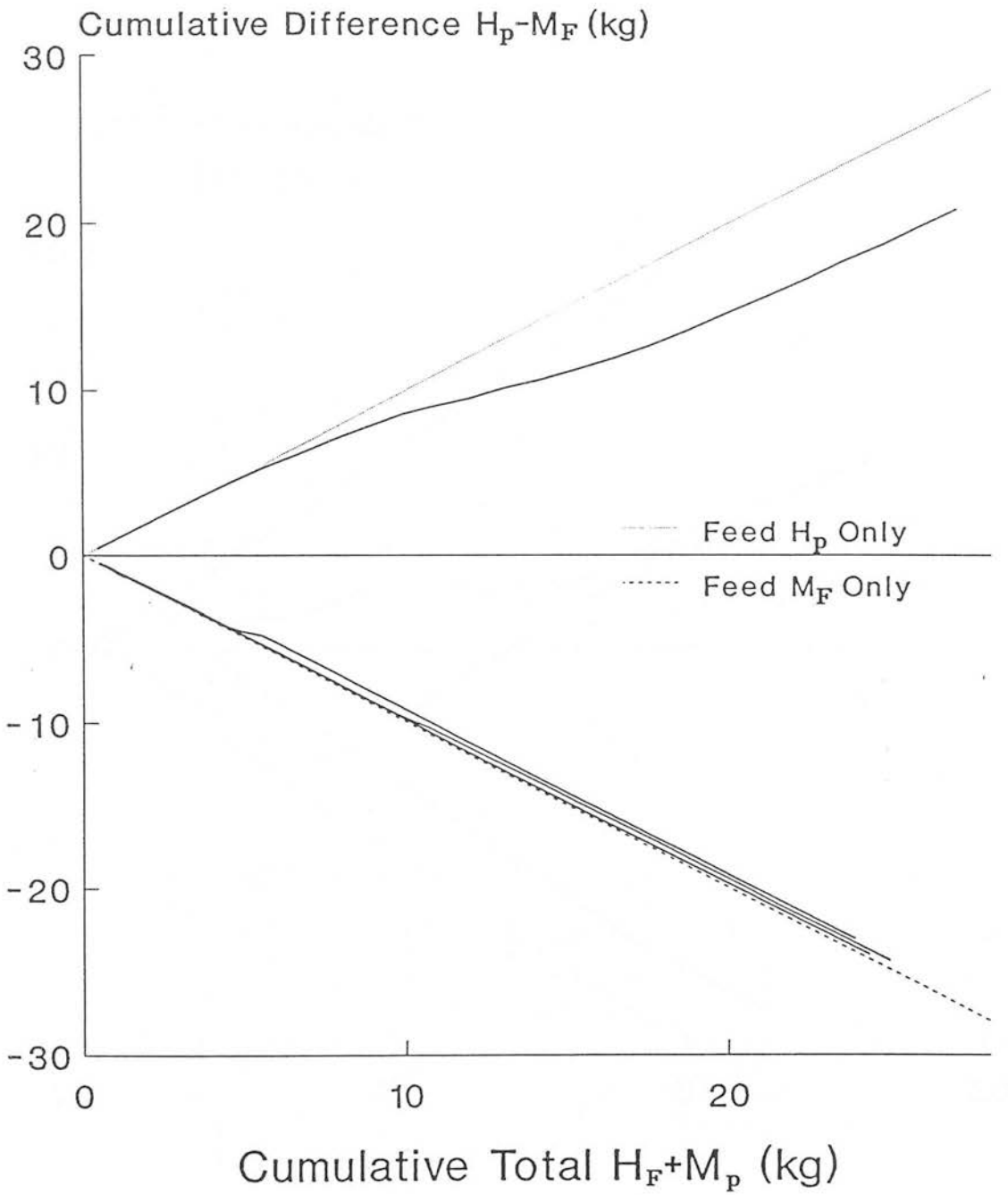


Figure 2.12 The paths of diet selection in growing pigs given a choice between feeds $M_F$ and $H_p$. Each line refers to an individual pig.

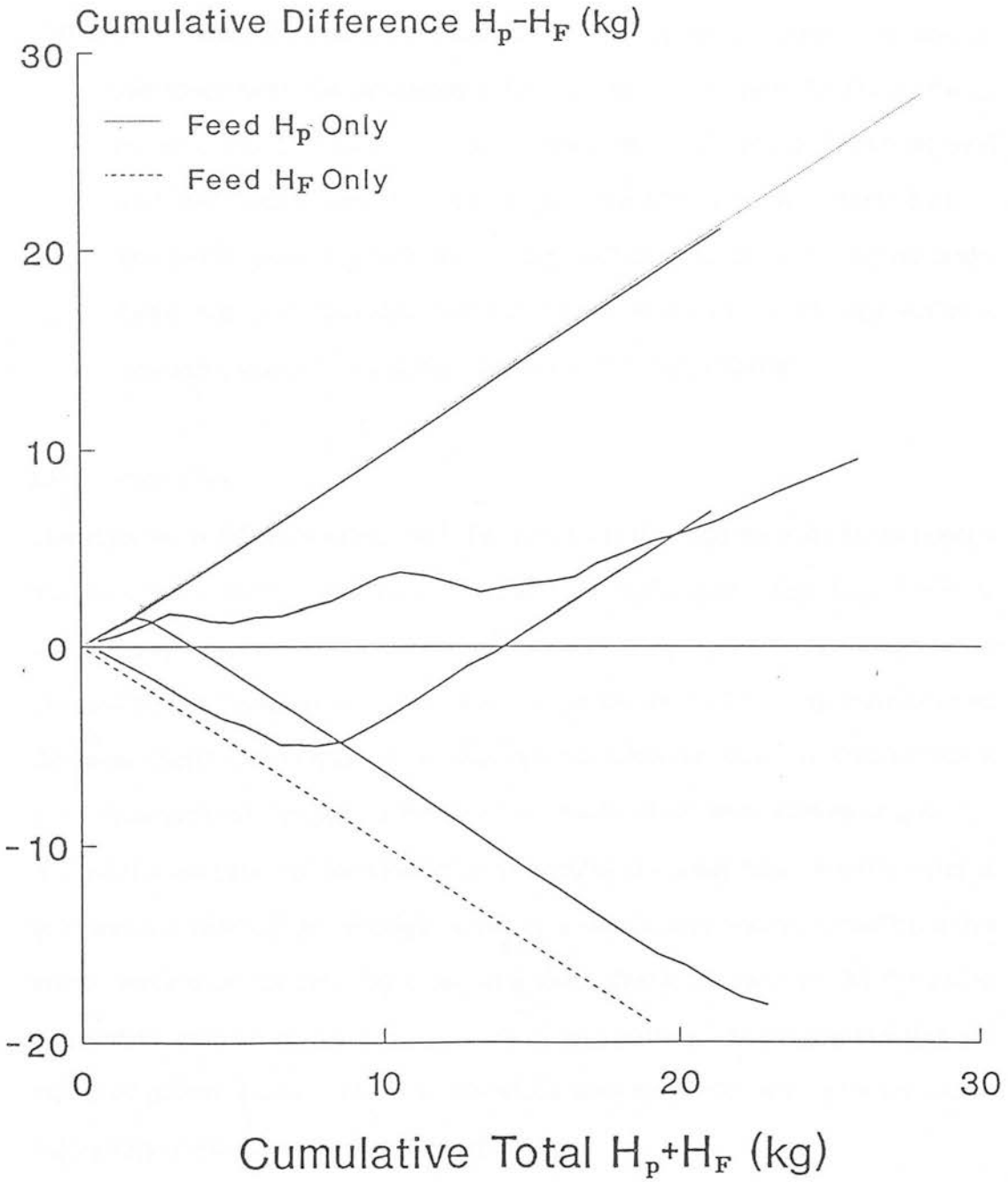


Figure 2.13 The paths of diet selection in growing pigs given a choice between feeds $H_p$ and $H_F$. Each line refers to an individual pig.

animals in each of the treatments $M_PH_F$ and $M_FH_P$ showed a marked preference for the medium protein feed only, but a fourth animal on each treatment consumed the high protein feed.

C1B-C3B Since the asserted propositions (P1B-P5B) did not survive the tests of this experiment, the corollaries (C1B-C3B) could not apply for the results of the experiment. Instead, a tabular presentation of their daily rate of total feed intake, daily rate of liveweight gain and FCE is given in Table 2.14. The performance of the choice-fed pigs reflected the choices that they made. There was a considerable variation in the performances of pigs within a treatment, which followed the variation in the diets selected.

### 2.9.5 Discussion

The experiment failed to substantiate the hypothesis that pigs are not able to select a diet that meets their requirement because they avoid feeds with high levels of inclusions of pruteen. However, the most important outcome of Experiment 2 was the considerable variation which was observed in the diets selected by individuals on the same choice (treatment). This variation was observed across treatments and it was independent of the protein source of the feeds which were offered as a choice. A careful examination of the diets selected revealed that some pigs were successful in their diet selection by: (a) choosing a diet of a certain composition, according to the protein content of the feeds on offer, at a given degree of maturity; (b) decreasing the protein content of the diets selected as they matured and (c) minimising the excess of protein intake. The question which then arose was: why were only some individuals successful in their diet selection?

A similar observation, that only some individuals of a group are able to select diets wisely, have led Dove (1935, 1939) to suggest that this ability was genetically determined. He coined the phrase 'aggridant type' to designate the nutritionally

TABLE 2.14 The average rate of feed intake, rate of daily liveweight gain and FCE of pigs given access to a pair of feeds, as a choice, from 12-30 kg liveweight (mean (s.e.))

| | Feed Pair | | | | |
|---|---|---|---|---|---|
| | $LH_P$ | $LH_F$ | $M_PH_F$ | $M_FH_P$ | $H_PH_F$ |
| Crude Protein selected (g/kg feed) | 209 (15) | 170 (26) | 246 (21) | 249 (22) | 322 (1) |
| Feed Intake (g/d) | 921 (24) | 952 (55) | 829 (34) | 904 (75) | 860 (95) |
| FCE (g of gain/ g of feed) | 0.677 (0.037) | 0.640 (0.066) | 0.779 (0.015) | 0.746 (0.026) | 0.776 (0.029) |

superior type of such an individual within a group. He suggested that this type was a 'leader-type', whose feeding behaviour was copied by the other members of the group, and in return the group as a whole was successful in their diet selection. To substantiate this hypothesis, Dove (1935) fed chicks on a mixed feed which was based on the choices of 'aggridant individuals' and produced exceptionally fast growth rates for the whole group. However, such a method reversed the argument, which was proposed for the use of choice-feeding as a potential feeding regime. It treats the 'aggridant type' as a predictor for the whole group, by ignoring individual differences; it suggests that choice-feeding could not be used successfully with single-caged animals, but only with group housed ones; and consequently implies that there is no theory which could predict the outcome of choice feeding experiments.

When the diet selection of each individual pigs was analysed on a daily basis (as in Figures 2.14 and 2.15) the following were observed. A successful individual, as pig No. 20 (Figure 2.14), consumed for the first few days only one feed (feed L in this case) and for the next few days showed a marked preference for the other (feed $H_p$). Subsequently, its diet selected was close to 50-50 per cent composition (equal amounts of $H_p$ and L) and it was then gradually diverted towards feed L, as it matured. On the other hand, pig No. 6 illustrated the typical behaviour of an unsuccessful individual (Figure 2.15). This pig did not sample feed $H_F$ (or consumed very small amounts of it) and therefore continued to favour feed L throughout the experiment, and consequently failed to meet its requirement.

The behaviour of such pigs was contrary to what was suggested by the diet-selection theory: that an animal will search amongst all the feeds on offer until it succeeds in acquiring a non-limiting or optimal diet for growth. Therefore, the question which was asked earlier was then reduced to: what inhibited these unsuccessful individuals from showing the expected exploratory behaviour?

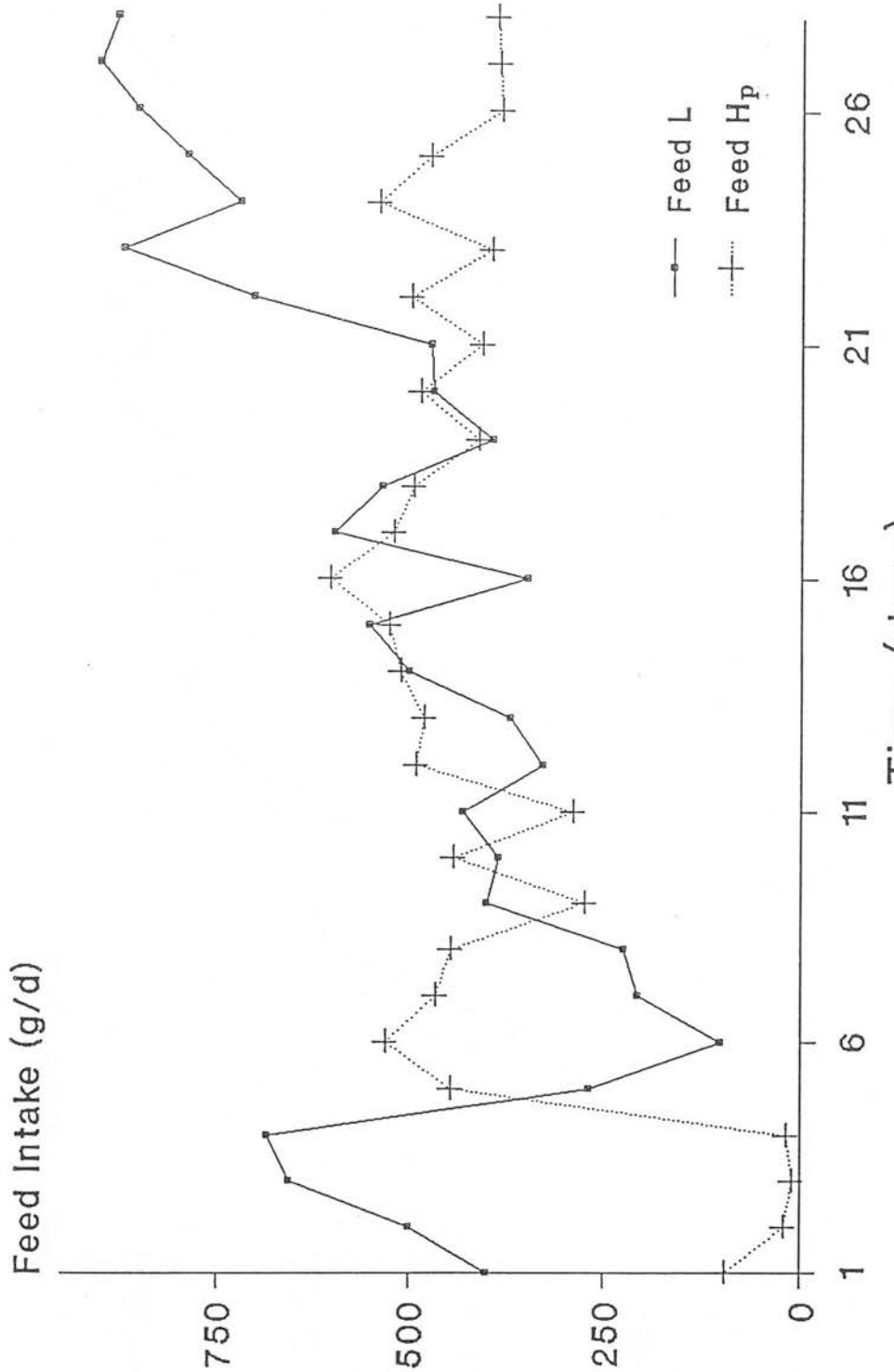


Figure 2.14 The daily feed intakes of pig No. 20 given a choice between feeds L and $H_p$.

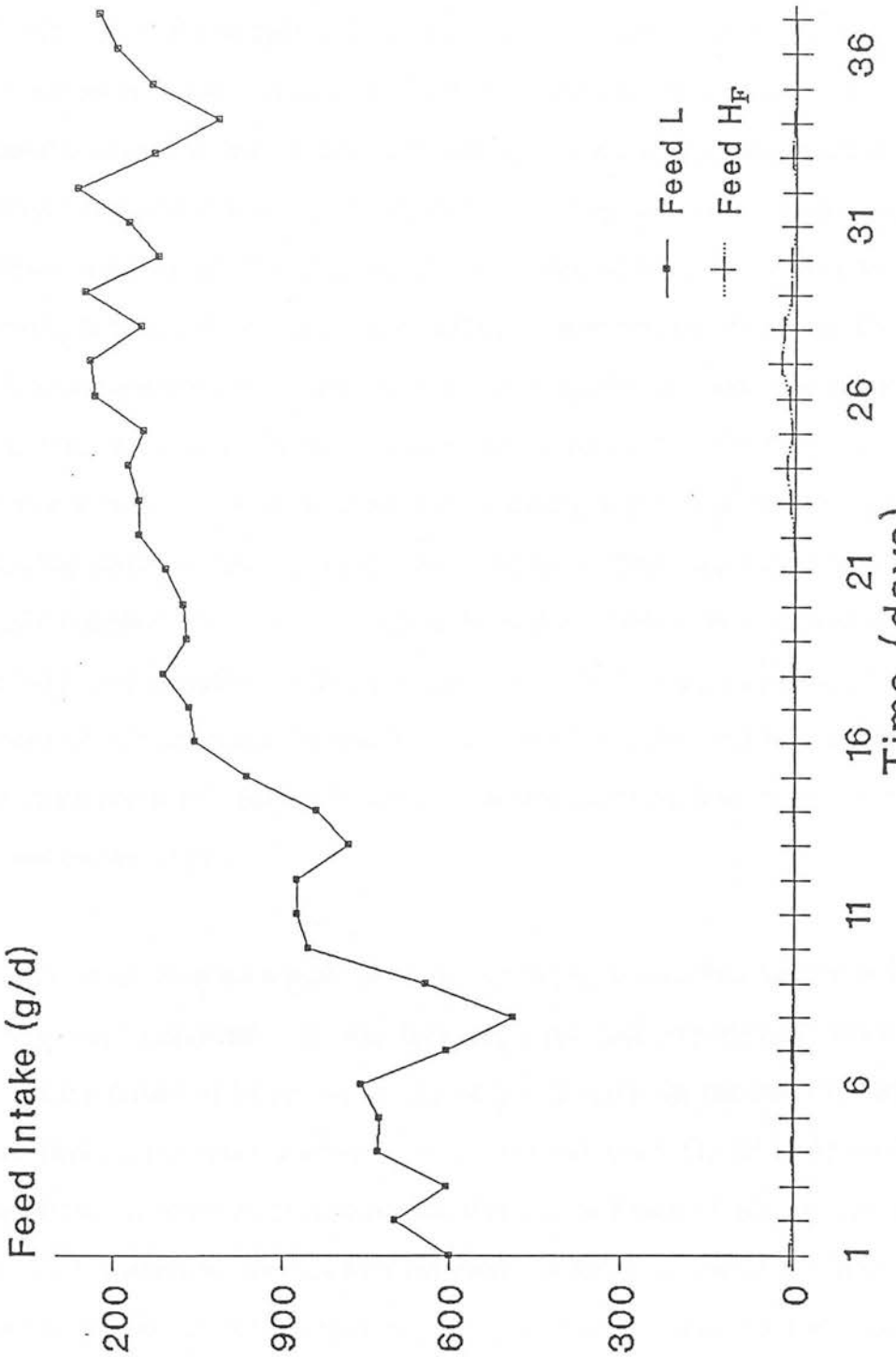


Figure 2.15 The daily feed intakes of pig No. 6 given a choice between feeds L and $H_F$.

An important observation, which unfortunately was not given sufficient attention in Experiment 1 was then better appreciated. When an animal avoided the feed in one trough, this always coincided with its contamination with urine or faeces. For the conditions under which the two experiments were performed, this behaviour (contamination of the trough) could be sufficiently explained. It is well known that pigs show specific sites for specific functions (Fradrich, 1974; Stolba, 1981, 1983). Eliminative behaviour (that of urine and faeces) does not take place at random in the territory: when confined to a relatively small pen, they use one corner (usually near the water drinker) for this purpose, and they tend to keep a dry area for lying (Signoret, Baldwin, Fraser and Hafez, 1975). Therefore, the design of the cages which accommodated two troughs imposed the following problem: pigs had spent a period from weaning to 12 kg liveweight having access to a single trough, which contained a high quality commercial feed. During this period they formed their eliminating areas, always around the water drinker. When the second trough was abruptly introduced at 12 kg liveweight, its position sometimes coincided with the areas used for elimination. Animals which continued to eliminate in these areas were consequently contaminating the trough. The contaminated feed was then avoided and the amount consumed, from this trough, was dependent on how quickly the fresh feed was contaminated.

This observation revealed a problem which had not occurred when the theory of diet selection was considered. It was then suggested that experiments which have reported the failure of an animal to select a diet that met its requirements belonged to the class of experiments where animals were not given the necessary choice to choose from. It seems possible, however, that a second class of similar experiments exist. This is where the animals were not given the necessary chance to choose. This argument centres on the problem of defining 'choice'. For example, scientists interested in an animal's perception of the feed, through its texture, taste or odour, have often measured a 'choice' on a short-term scale of minutes or hours, which may

not bear a direct relationship to the longer term nutritional consequences of taking that feed. However, the idea of free choice-feeding, as used in this thesis, implies that an animal is given free, continuous and undisturbed access to a set of fresh feeds from which it can select its diet. At this stage, it is reasonable to suggest that an animal takes some time, perhaps days, to choose a non-limiting diet, since a delay in response to the nutritional effects of a certain choice must be expected from the knowledge of the digestive and assimilative processes in the animal. In addition, the animal may use cues during the search for feed, such as the taste or the position of the feed, to help guide them in future choices to whatever stuff has been previously experienced as nutritious (Young, 1945).

The above idea can account for the diets selected by the pigs in Experiment 2 and by the pigs in Experiment 1 before the change in the position of the troughs at 24 kg liveweight. Animals failed to select a diet that met their requirements because they did not have the necessary chance to choose, since one of the two feeds was always contaminated and therefore avoided. However, it cannot account for the observation that pigs continued to avoid feed H in treatments MH and LH (Experiment 1) and therefore selected a similar diet before and after the change in the position of the troughs. It is possible, however, that during the 12 to 24 kg liveweight interval animals recognised as a potential feed only the one that they consumed. This association guided them to follow the feed and not its position after the reversal, a fact which is supported by the immediate response to change. This was only possible if pigs simultaneously changed their areas of elimination, a situation that has often been reported for pigs (Craig, 1981). Unfortunately, this hypothesis could not be tested since the areas of elimination were not recorded in Experiment 1.

The above argument implies that other factors, as well as nutritional ones, such as the relative position of the feed, the duration of the experiment, the familiarity of the feed, may affect the outcome of a choice feeding experiment. However, even

though experience and habit must be considered strong influences in preventing nutritional readjustment, nevertheless both experience and habit, if properly directed, perhaps may be made to serve well the purpose which they were designed by nature, through survival, to serve.

# CHAPTER III

## A RE-ASSESSMENT OF THE THEORY OF DIET SELECTION

## 3.1 INTRODUCTION

In the last chapter it was suggested that an animal may need to sample both feeds on offer before selecting a non-limiting diet, and that control over diet selection may need to be learned. Such an idea implies that an animal may take some time before selecting a non-limiting diet, but this is not considered sufficient grounds for dismissing the notion of 'nutritional wisdom'. In fact, it has long been argued that the control over diet selection is learned and that: 'there is no instinctive discrimination. What shall be selected for eating and what rejected is a matter of individual experience' (Morgan, 1894).

Indeed, it is unthinkable that specific innate mechanisms exist to handle the full range of diet selection in animals. For each nutritional component, there would then have to be a unique specific sensory message and a unique central state characterising the deficiency and sensed by a specific detector. The incredible amount of machinery needed for this would, for the most part, remain unused during the lifespan of the animal, since it is probable that a given animal does not experience most specific nutritional deficiencies in its lifetime.

In the past, the main argument in favour of these innate-type mechanisms was the inability to find a reasonable explanation for the way that animals learn what to eat and how much to eat. In this chapter, evidence against this argument, and in favour of the idea that animals learn to select a non-limiting diet will be given. In addition, some possible explanations for how animals learn their feeding habits will be discussed.

## 3.2 EVIDENCE FOR LEARNED FEEDING HABITS

The majority of the evidence is derived from experiments with rats and mice. This may reflect the assumption that these animals were always supposed to possess the

ability to select a diet which could support their potential growth (for the young) or maintain themselves (for the adults) (Overmann, 1977). The investigation into their learning behaviour was often an attempt to explain the apparent contradiction of this assumption.

Probably the best demonstration of the fact that animals need to acquire information about the feeds before making the 'correct choices' are the experiments by Harris, Clay, Hargreaves and Ward (1933). In their detailed investigation, Harris *et al* (1933) dealt with thiamine deficient rats, offered a choice between a thiamin deficient and a thiamin containing feed. Usually, these animals did not have any problems in selecting the latter feed and consequently recovering from the deficiency. However, when the number of choices was increased (a choice between six or ten feeds, but only one thiamine containing) some of the deficient rats failed to choose the beneficial feed. At this stage, Harris *et al* (1933) introduced the 'education period', where animals were offered the thiamine containing feed for two or three days. Following the 'education period' all the rats successfully selected the thiamine containing feed and recovered from the deficiency, irrespective of the number of choices or the thiamine source. It is probably worth saying that for their control animals (rats that were not vitamin depleted, since they were given thiamine separately) the 'education period' did not play any significant role in their diet selection. These rats were able to thrive on any of the feeds and continued to eat the feeds indiscriminately.

Similar evidence derives from the experiments of Leathwood and Ashley (1983a, b) on protein selection of weanling and adult rats. They offered rats a choice between a protein-free and a high protein feed; all the animals had the opportunity to select a non-limiting diet, since the high protein feed was over-abundant. Their detailed observations were summarised as follows:

(i) All rats consumed both feeds on the first day of the experiment.

(ii) Some rats chose an adequate amount of protein from the first day.

(iii) The others (36 out of 64) preferred to eat most of their diet from the protein-free feed.

(iv) Those that ate inadequate amounts of protein began to lose weight and became anorectic.

(v) After three to ten days, these animals abruptly began to eat adequate amounts of protein. They immediately increased their feed intake, resumed body growth and continued to thrive.

From their observations Leathwood and Ashley (1983a) concluded that the initial choice was based on individual preferences, not on long-term protein needs. Adequate protein selection could occur either by chance (ie. because the individual preferences coincided with physiological needs) or through learning.

The list of this kind of evidence, derived from experiments on rats and mice, could be a very long one. However, rats and mice are not the only species who learn how to be successful in their diet selection. Here, two more examples involving other species (ie. pigs and chickens) which provide similar evidence will be described. This evidence is not as direct as that from the rats and mice experiments, since it does not derive from diet selection experiments, is, however, of a similar value because it demonstrates the need for an animal to acquire information about its feed before making the right decision.

Blair and FitzSimons (1970) in attempting to limit the feed intake in a group of pigs, offered *ad libitum* access to single feeds impregnated with different levels of Bitrex 'the bitterest substance known to man'. Their theory was that animals do not like bitter feeds, and will therefore decrease the rate of their feed intake when given such feeds. This assumption was not unsound since often in nature animals show an

aversion to bitter tastes (Steiner, 1973) which may owe its existence to the selective advantage enjoyed by animals which spontaneously rejected the (often poisonous) bitter alkaloids which are widely distributed in the plant kingdom. However, the pigs showed only a transient avoidance of the Bitrex-impregnated feeds. Later, on discovering that eating the bitter feed was harmless, their hunger and physiological needs overpowered the misleading sensory cue, and they ate the feed. Blair and FitzSimons (1970) reported that there were non-significant differences in total feed intake between the untreated and treated feed groups. It is quite unfortunate that the way of data presentation allows only speculations about the duration of the learning period. Their findings, however, are consistent with the outcome of later experiments on rats, where the aversion to a bitter tasting feed was changed by experience, when this feed was associated with positive metabolic effects (Kratz, Levitsky and Lustic, 1978).

Finally, the ability of young chickens to learn to identify water visually was shown in experiments by Hunt and Smith (1967). Young, naive chickens, virgin with respect to water and rather dehydrated, would run through puddles of water without recognising them. However, chicks have a built-in tendency to peck at small irregular objects (eg. grains) (Breed, 1911). When an irregularity happened to occur occasionally in water, and water got into their bills as a result of pecking, the chicks immediately began drinking and drank an amount approximately equal to their water deficit. From that moment on, since the association between water and its direct consequences was rapidly made, water was recognised visually.

## 3.3. THEORIES OF LEARNING

In the wild, young animals learn what to eat from their parents. It has been shown that if parent rats avoid feed A and consume feed B, their infants at the time of weaning and separation will follow the same preference pattern (Galef and Clark,

1971). The same seems to hold for domesticated species, at least when they are kept in extensive conditions, since the ewe appears to influence the diet selection of the lamb for the period following weaning (Hinch, Lecrivain, Lynch and Elwin, 1987). This behaviour can be explained in terms of familiarisation (Rozin, 1976). The young become familiar with the feeds their parents consume when they graze in the environment along with them, or with some salient characteristics of the feeds which are eaten by the mother and appear in her milk (Galef and Sherry, 1973).

Learning through familiarisation could apply for most of the species in the wild. Certainly it must be the only way that specialist species, which eat a narrowly circumscribed group of feeds (eg. the koala bear), learn to recognise their feed. However, in modern husbandry practices, the young animals often do not have the opportunity to become familiar with the feeds in a similar way. Young pigs are abruptly weaned from their mothers and have to cope with the abrupt change from their mother's milk to a solid feed. Probably the only previous experience with solid feed was the spillage from their mother's trough, or her faeces. For these circumstances another type of learning must account for how animals learn what and how much to eat, and subsequently make the correct dietary choices. Two current theories that have evolved to account for this type of learning are considered below.

### 3.3.1 Feed-aversion Learning

The feed-aversion learning theory, first suggested by Rozin (1976), proposed that animals learn to avoid what is harmful for them; they, thus, learn from their mistakes. The feed aversion theory was based on observations of how rats learned to avoid poisons. In a detailed series of experiments, Garcia and Koelling (1966) had shown that rats were able to associate malaise induced by a feed with its taste and smell. Consequently, they were able to avoid the toxic feed by recognising its organoleptic[3] properties. The developed aversion was strong and it was demonstrable

[3] *This term applies for the properties of the feed that are perceived by the senses, eg. colour, taste, texture.*

even if the symptoms were developed several hours after the consumption of the feed (long-delay learning). According to Garcia, McGowan and Green (1972) this long-delay learning was unique and characteristic of the feed-aversion learning. Only in the feeding system are the initial events (tastes or smells) separated significantly from their metabolic consequences, since the gut induces an inherent delay. In the rest of life (eg. predator avoidance) causes and consequences follow rapidly in time.

Rozin (1976) extended Garcia's findings and applied the feed-aversion paradigm to the choice feeding situation. When he offered (Rozin, 1965) a choice between a thiamine-deficient and a thiamine-rich feed to thiamine deficient rats, he observed that rats consumed only the latter. Their preference for the thiamine-rich feed persisted even after the rats had recovered. He suggested that the behaviour of these rats could be explained as follows: vitamin-deficient feeds act like slow poisons and therefore animals become aversive to them. The preference for the thiamine-rich feed, manifested after recovery, was a retained aversion for the deficient feed and not a preference for the enriched feed, which had stopped being beneficial since the animals' recovery.

Rozin (1976) defended his theory with examples from other species, such as cattle (Zahorik and Houpt, 1977) and poultry (Wilcoxon, Dragoin and Karl, 1971), where feed aversion seemed to apply. His theory was adequate enough to explain how animals learn to choose between a mineral or a vitamin deficient feed and an adequate feed (eg. Rodgers, 1967), a protein-free or an amino acid imbalanced feed and a protein balanced feed (eg. Leung *et al*, 1968), and why they become anorectic when on a deficient feed. In all these cases the deficient or imbalanced feed acted as a poison which the animal learned to avoid. However, the feed aversion paradigm could not apply to more complex situations, when the animal is presented with a

variety of feeds that produce significant positive or, at least, non-negative effects, as in cafeteria feeding. Rozin (1976) himself had to accept the inadequacy of the theory and proposed that:

> 'although the major phenomenon appears to be learning about aversive consequences of deficient feeds, animals must be able to learn (as well) about the positive effects of feeds'.

### 3.3.2 Feed-preference Learning

In its simplest and historically most commonly accepted form, a learning explanation of feed-preference conditioning assumes the following sequence. An animal is deficient in nutrient X and presumably feels sick. It encounters, among other feeds, a feed containing X and eats some. It starts feeling better and is, thus, reinforced for eating X; hence a preference for X (or for the feed containing X) develops.

This theory was suggested as early as 1938 by Richter *et al* (1938). However, in spite of some experimental evidence by Harris *et al* (1933) and Scott and Verney (1947), who had demonstrated something like this, the difficulty and the conflict with basic learning principles did not convince psychologists that feed preferences could be learned. Furthermore, when the feed-aversion theory was suggested, the ease of establishing such aversion conditioning contrasted with the difficulty of conditioning preferences, and left the impression that aversion was easier to condition than preference or even that genuine absolute preferences could not be generated by associative conditioning (Zahorik, 1979).

Such a view, of course, could only be substantiated by ignoring how ill the animals are in deficient or the toxic states and the results of many other experiments using milder conditioning states that are more common in nature (Booth, 1985). Gross deficiency of a vitamin or a mineral, or the administration of a toxin, creates a

complex pathological state that will, at best, be only partly normalised after administration of the deficient nutrient or cessation of toxin administration. Even though overt behavioural symptoms may have subsided, it is surprising that partial 'recovery' conditions the slightest preference at all. That it sometimes does may indeed be evidence for a relative theory of reinforcement - improvement from very bad to bad, is sufficient to condition preference.

The difficulty of demonstrating conditioning preferences may also reflect the limits imposed on this type of learning. Preference conditioning must have an optimum strength, beyond which the organism is receiving excess of nutrient intake. Sufficient excess of even an essential nutrient can be toxic (Peters and Harper, 1987). In contrast , the conditioning consequence in aversion learning has no upper limit (except that the organism recovers sufficiently to be testable for learning later).

Two studies (Seward and Greathouse, 1973; Booth, 1985) that have tried to compare directly the two directions of conditioning have given contradictory results. This may reflect the difficulty of making a legitimate comparison of the strengths of the aversion and preference conditioning. Any attempt at comparison must be founded on a demonstrable equality of the strengths of the two sorts of conditioning consequences. It may also reflect the arbitrary and subjective manner in which these experiments are interpreted, especially as it is often not very clear whether a preference or an aversion for a feed has been established.

Recent evidence (Revusky, 1967; Gibson and Booth, 1986; Baker, Booth, Duggan and Gibson, 1987) supports the idea that animals develop preferences for a feed. An odour-preference conditioned by the effects of ingested protein on mild protein deprivation was only seen when such deprivation recurred (Gibson and Booth, 1986). This protein-conditioned odour preference was not seen if protein was infused prior

to the test for learning, but it was evident if an equicaloric amount of starch was pre-infused prior to the test.

The paradigm of feed preference conditioning can then apply to experiments where the animal has to select a diet between a set of feeds (by eating a substantial amount of feed from each trough) to meet its requirements. This implies that the animal will get sufficient amount of a nutrient or nutrients and at the same time will avoid excess of nutrient intake. The translation of a learned preference into a physiological mechanism, although it is very interesting by itself (Fernstrom, 1987), is not the subject of this review.

## 3.4 IMPAIRMENTS TO LEARNING

Both theories conclude that learning is established through associations. Animals associate some organoleptic properties of the feed with its nutritional consequences. Booth (1985) supplied a list of properties of the feed which had a significance in establishing associations. These properties were the odour and the taste of the feed, and the position of the feed trough. To his original list we can add the texture, the form and possibly the colour of the feed.

It is well known that animals exhibit strong positional preferences (Hughes and Wood-Gush, 1972) and that their diet selection might be affected by the position of the trough in relation to the water bowl, or the relative illumination of the trough (Krauss and Mayer, 1964). To control for these preferences the position of the feeds is often changed, but if its relocation is more frequent than the time interval which the animal takes to learn the consequences of mistakenly choosing the wrong feed (by following the position cue) it is possible that the animal will fail to choose a diet which matches its requirements (Wood-Gush and Kare, 1966; Vohra and Heil, 1969)

or it will prolong the learning period before making 'correct' dietary choices (Hughes and Wood-Gush, 1972).

A similar confusion for the animals may be caused in experiments where the odour or taste of a feed has been masked by impregnation with an essential oil or artificial sweetener (Simpson and Booth, 1974; Lee and Hill, 1983). The usual reason given for this impregnation is that some feedstuffs are 'unpalatable for the animals' and their taste needs to be masked for the sake of correct choices. However, what scientists mean by 'unpalatable' is either what they imagine is not 'tasty' for the animal or some other properties of the feed, apart from the taste, that have a direct bearing on the feed intake (Hill, 1979). (This argument has been already elaborated in the previous chapter).

Therefore, the time interval which an animal takes to form associations can be prolonged unintentionally when the animal, is not given sufficient cues. This time interval must be characteristic of a species and be correlated with the size of the animal. A small sized animal (eg. a rat) which has a faster rate of living and metabolism (Thompson, 1917; Brody, 1945) is likely to be less affected by a daily change in the position of the feeds, than a larger animal (eg. a pig). The experimental evidence supports this view, since rats and mice were unaffected in meeting their requirements by the daily alteration of the position of the feeds, when they were provided with other cues (Richter *et al*, 1938). The time interval can also be affected when the number of choices is increased. In the simplest form of diet selection - a choice between two feeds - an animal is probably able to form associations by using relatively few cues. When the number of the choices is increased, sometimes up to ten different feeds, the animal has to sample all the feeds and form more complex associations. Experiments with large numbers of choices have often been characterised by the failure of the animal to select a non-limiting diet simply because animals were not given sufficient time to learn (Harris *et al*,

1933) and the observations ended too soon (Kenney and Black, 1984). In Evvard's (1915) experiment, for example, pigs needed a period of twenty days to form associations and consequently choose a non-limiting diet between the ten feeds.

Thus, Krebs and McCleary (1984) and Blundell and Hill (1987) have criticised experiments in which the animals are tested in 'unnatural conditions', particularly when the animal is 'tricked' during the making of its choice. Blundell and Hill (1987) have suggested that the failure to demonstrate successful diet selection in the laboratory might be due to inadequate experimental designs or experimental techniques too crude to reproduce conditions which lead to the success of animals in the wild. The need for a learning period has often been ignored in choice-feeding experiments and animals have not been given the opportunity to acquire information about their feeds. In addition, what has often been considered as the inability of animals to learn and consequently choose a non-limiting diet, can be seen as an artefact of the experimental design. The length of the time that the animal will take to learn what diet is a non-limiting one can be considered within the boundaries of a learning theory, and learning can be seen as the tool by which animals achieve targets: in this case to grow protein at their potential and lipid at their desired rate.

## 3.5 CONSIDERATIONS FOR THE EXPERIMENTAL COMPONENT OF CHAPTER 3

Although the need for an initial learning period, before animals make 'correct' dietary choices and some of the necessary and sufficient condition for learning were previously discussed, the problem of ensuring that animals have sampled all the feeds on offer and the question of precisely how much sampling an animal needs to do, remain to be considered.

It has been suggested that group-housed animals are more 'successful' than individually caged ones in selecting a diet which meets their requirement (McDonald, Stem and Hahn, 1963). This is probably because animals tend to copy each other (Lat, 1967), a behaviour which has often been characterised as allelomimetic[4]. Therefore, an experienced individual or one who will sample all the feeds, is needed to ensure 'correct' dietary choices by all the members of the group (Gous, 1988; personal communication). However, group housing makes it difficult to observe any individual characteristic relating to feed intake and the potential growth of the animal, and needs to ensure that each member of the group has free, continuous and undisturbed access to all of the feeds.

A second possible way of ensuring that animals have experienced all the feeds on offer, is the method used by Harris *et al* (1932) and repeated by Krauss and Mayer (1964). In these experiments the animal was given access to one feed only, for a certain period of time, before it was offered two feeds as a choice. The time needed to be sufficiently long, usually 2 to 3 days, to ensure that the animal will consume some of the feed. The choice offered to rats was between an 'adequate' and an imbalanced feed, and the experience was given only on the former feed. This method was probably a very simplified way of sampling, since the animals did not need to experience the imbalanced feed as well, in order to make successful choices and it can therefore be argued that animals were selecting the familiar feed.

However, when an animal needs to consume a certain amount from each feed in order to select a non-limiting diet, the problem of predicting the amount of necessary sampling and consequently the length of the experience period, or how often it has to be repeated, is a complex one, even in an environment with known

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4 *Allelomimetic behaviour has been defined as the behaviour exhibited by two or more animals, doing the same thing at the same time with some degree of mutual stimulation (Wood-Gush, 1983).*

properties (Staddon, 1983). Nevertheless, the main factors involved in such a prediction are straightforward:

(a) How much does the animal already know?

(b) How many factors can it assess on each sampling trial?

(c) How important are the consequences of learning?

(d) What is the cost of sampling?

Most of these questions have already been considered earlier in this chapter, when the impairments of learning were discussed. When the animals are to be given a choice between a limiting and an abundant feed, the above questions can be rephrased as:

(i) Should the animals experience one or both feeds before they will be given both as a choice?

(ii) If it is to be given experience on only one feed, which one is it to be?

According to the method of Harris *et al* (1932) only the feed with the least sampling cost must be experienced. However, in a choice between two feeds different in crude protein, sampling of either feed carries some cost: slow growth on a deficient feed and excess of nutrient intake on the abundant one. In addition, experience on one feed only may give the same results as those seen in Experiments 1 and 2, where the second feed, after its introduction, was ignored. Therefore, it seems more logical to suggest that an animal has to experience both (or all feeds) before being offered the choice. In this case, three further questions are to be considered:

1. What is the order in which the feeds are to be experience?

2. What is the duration of the experience on one feed?

3. Does the experience period have to be repeated more than once?

An experiment designed to consider all these factors and answer these questions, some of which are fundamental questions of a learning theory (Staddon, 1983) and beyond the purpose of this thesis, would involve a large number of animals and treatments. However, since the experimental facilities available were limited to twenty cages which could accommodate two troughs, it was felt necessary to reduce the number of factors to be investigated. A period of one day on a feed was considered sufficiently long to ensure that a pig would sample the feeds. A period of six days experience on a feed was also considered sufficient for the pig to associate the feed with its properties, since pigs successful in their diet selection experienced each feed for a period of three to four days (Chapter II). In addition, a period longer than six days could also be expected to have an appreciable effect on the body composition of the animal and consequently its diet selection. Therefore, two methods of experiencing the two feeds were investigated:

(i) The animal will first experience one feed for a period of six days and then the other for an equal time period. Such a method comprised two treatments, depending on which feed will be offered first.

(ii) The animal will experience the two feeds, each on alternate days, for an equal period of time.

(iii) A fourth treatment was considered necessary. That, where the animals will be offered the two feeds immediately after the pre-experimental period, without having any previous experience of them. This treatment will be a control treatment, since it reproduces the method used in Experiments 1 and 2.

In addition, a control series of single feeds of different protein content allowed the effects of this factor on feed intake to be measured.

## 3.6 EXPERIMENT 3: A REASSESSED TEST OF THE THEORY OF DIET SELECTION

### 3.6.1 Materials and Methods

The housing and management procedures were identical to those described in Experiments 1 and 2. Any changes in the routine are described below.

*Animals*. Forty Cotswold Large White x Landrace pigs (20 entire males and 20 females) from 6 litters were individually caged in the controlled environment portacabin used for the previous experiments. The animals were moved immediately after weaning (at 4 weeks of age) and did not have any previous experience of creep feed.

*Feed*. Two basal feeds with different CP levels (a low and a high) but with similar energy content, were formulated and made into pellets (Table 3.5.1). The low protein feed (L) was formulated to be inadequate in protein to support potential growth, when offered single *ad libitum* (ARC, 1981). This feed was similar (in CP terms) to the low protein feeds used in Experiments 1 and 2, but only two major ingredients were used here: oatflakes and milk replacer. The second basal feed (H) was made with a higher CP content, intended to be above the requirements of the pigs, by substituting herring meal and milk replacer for the oatflakes of feed L. Both feeds were intended to be non-limiting in minerals and vitamins, but feed H contained a higher amount of minerals (to maintain suitable ratios to protein).

The two step mixtures of feeds L and H were also made, to produce feeds A and B. Feed A contained 0.67 L and 0.33 A; feed B was a mixture of 0.33 L and 0.67 B. The four feeds (L, A, B and H) were pelleted individually and analysed for dry matter and nitrogen, ash and ether extract in the dry matter. The chemical analyses of the feeds are shown in Table 3.5.2. The estimated CP values (N x 6.25) by the

**TABLE 3.5.1 The composition of the four feeds (kg/tn fresh weight) used in Experiment 3.**

| Ingredients (kg/tn) | FEED | | | |
|---|---|---|---|---|
| | L | A (2/3L+1/3H) | B (1/3L+2/3H) | H |
| Herring Meal | - | 75 | 150 | 225 |
| Oatflakes | 727 | 600 | 437.7 | 347 |
| Milk replacer | 185 | 240 | 295 | 350 |
| Molassses | 50 | 50 | 50 | 50 |
| PT10C Vitamin and Mineral supplement[a] | 5 | 5 | 5 | 5 |
| Vit E supplement | 7.5 | 8.5 | 9.5 | 10.5 |
| Salt | 2.5 | 2.5 | 2.5 | 2.5 |
| Dicalcium Phosphate | 23 | 19 | 14.3 | 10 |
| | 1000 | 1000 | 1000 | 1000 |

a see Table 2.3

**TABLE 3.5.2 The chemical analysis of the four feeds (g/kg fresh weight) used in Experiment 3**

| Component (g/kg) | FEED L | A (2/3L+1/3H) | B (1/3L+2/3H) | H |
|---|---|---|---|---|
| Digestible energy[a] (MJ/kg) | 15.8 | 16.3 | 16.7 | 17.1 |
| Dry Matter | 901 | 896 | 900 | 907 |
| Crude Protein (CP) | 125 | 166 | 222 | 266 |
| Ether Extract | 81 | 77 | 89 | 99 |
| Ash | 58 | 77 | 74 | 84 |
| Fibre (NDF) | 45 | 43 | 61 | 58 |
| Gross Energy (MJ/kg) | 16.8 | 16.5 | 17.6 | 18.0 |

a values calculated from feed tables

analysis were regressed on the proportion of feed H they contained (0, 0.33, 0.67 or 1 respectively). The regression equation derived was:

Food CP content = 121 + 141 (s.e. 4.7) x prop. H g/kg of fresh food ($r^2 = 0.996$)

The CP values were recalculated by this equation and the small differences between calculated and measured values were attributed to mistakes in the analysis of the feeds. The calculated values were then used as the corrected CP content of the four feeds, for the analysis of the results.

A dilution series of feeds has a number of advantages over the formulation of individual feeds. Errors in formulation, mixing or chemical analyses, are more easily detected. Feed formulation is simplified to that of the two basal feeds, and since the two feeds differ in one nutritional variable (CP content in this case) any range of feeds between the two basal can be mixed simply by proportion.

**Methods:**

*Pre-experimental Period*. The pigs had a mean liveweight of 6.78 kg (s.d. 0.67) when they were moved into the cages. The pre-experimental period lasted for 17 days (s.d. 3 days) on average. During this period, four animals died with colibacillosis and were replaced by animals from another litter.

*Experimental Design.* The experiment was in two parts, the single and the choice-fed pigs, and lasted for 36 days, from 12 kg liveweight. The animals were randomly allocated to the treatments, taking account of age at 12 kg and with a restriction for litter origin. Each treatment was balanced for sex.

(i) *Single-fed pigs*: Each of the feeds was offered singly *ad libitum* to four pigs (treatments L, A B and H). In addition, four more pigs were given feeds L and H alone *ad libitum* on alternate days (treatment AT).

(ii) *Choice-fed pigs*: These pigs were given one of four treatments (T1-T4) (Table 3.5.3); each treatment consisted of two periods.

T1: Feed H for 6 days, followed by a choice between L and H for 12 days (Period I).
Feed L for 6 days, followed by a choice between L and H for 12 days (Period II) (n = 4).

T2: Feed L for 6 days, followed by a choice between L and H for 12 days (Period I).
Feed H for 6 days, followed by a choice between L and H for 12 days (Period II) (n = 4).

T3: Feeds L and H alone on alternate days for 6 days, followed by a choice between L and H for 12 days (Period I). Period II was a repeat of Period I (n = 6)

T4: A choice between L and H throughout (n = 6).

*Management*. The position of the feeds did not change throughout the 36 day period, but their position was randomised across pigs. The animals were weighed daily (during the morning) up to the 24th day and then twice a week (Mondays and Thursdays). They were fed twice a day (morning and afternoon) and the feeding routine started at 9 am and followed the same animal sequence. The weighing started immediately after feeding and also followed the same animal sequence. Feed

TABLE 3.5.3 The Design of Experiment 3 (Choice-fed pigs)

| Treatment | Period I | | Period II | |
|---|---|---|---|---|
| | Experience (6 days) | Choice (12 days) | Experience (6 days) | Choice (12 days) |
| T1 | H | LH | L | LH |
| T2 | L | LH | H | LH |
| T3 | L and H | LH | L and H | LH |
| T4 | ← LH → | | | |

refusals were weighed daily and discarded; for wet refusals the dry matter was measured.

Outside temperatures below $0^{o}C$, which were present during the last part of the experiment (January 1987), caused a blockage in the water supply system, due to frozen water. Therefore, the experiment had to be abruptly discontinued and some animals spent only 34 days on the experiment. For the purposes of the statistical analysis a 34-day period was considered for all the animals.

### 3.6.2 Propositions and Corollaries

(a) **Single-fed pigs**

P1 Pigs will increase the rate of feed intake at a weight, as the protein content of the feed is decreased below the requirement.

P2 When feeds L and H are alternated daily (treatment AT), pigs will consume a higher amount of feed when they have access to L rather than H.

C1 The rate of the increase in feed intake, as the protein content of the feed is decreased, will be predicted by the Feed Intake Model.

C2 Pigs on the high protein feeds will grow at a rate set by their inheritance, ie. they will achieve their potential rate of growth.

(b) **Choice-fed pigs**

P3 Pigs that have experienced both feeds (treatments T1, T2, T3 in Period II and treatment T3 in Period I) will choose between the two feeds on offer in a directed manner.

P4 The above pigs will select a diet of a certain composition, according to the protein content of the feeds on offer, at a given degree of maturity.

P5 The protein content of the diet selected will decrease as the pigs mature.

P6 When pigs have not had any previous experience of the feeds on offer (treatment T4) the diets selected by individual pigs will vary more than where they have had such experience.

Should propositions P3-P5 survive, the theory predicts that pigs which have experienced both feeds would select a common diet, their growth will not be first limited by a nutrient, in which case, the following corollaries apply:

C1 These pigs will have a similar total feed intake, which will be predicted by the Feed Intake Model.

C2 These pigs will grow at a rate set by their inheritance and have a similar Gompertz liveweight gain rate parameter, expected to be 0.01395 per day (from Chapter I).

### 3.6.3 Results

#### (a) Single-fed pigs

*Feed Intake*

P1-C1 Since the experiment was carried out on a time basis, the 20 kg liveweight was chosen for comparison of the daily rate of feed intake at a weight. The rate of feed intake at 20 kg liveweight (the values reported here represent the average of 9 days) increased as the protein content of the feed was decreased from H to L (Table 3.5.4). The increase, the results being treated as from an experiment of randomised design with feed crude protein level as variate and sex as covariate, was essentially linear ($p<0.05$) and there were no significant effects of sex nor any sex x feed crude protein level interactions. A similar increase (linear; $p<0.05$) was also apparent in the short period of the first 10 days, but the animals consumed similar total amounts of feed on each treatment during the entire 36 day experimental period.

**TABLE 3.5.4 The actual and predicted rates of feed intake at 20 kg liveweight, and the average rate of feed intake of pigs given access to a single feed in the first 10 days and in the 36 day experimental period (mean (s.e.))**

| Rate of feed intake (g/d) | Feed L | A | B | H | s.e.d |
|---|---|---|---|---|---|
| At 20 kg liveweight: | | | | | |
| Actual[1] | 1164 (41) | 1074 (71) | 1016 (55) | 946 (13) | 74 |
| Predicted[2] | 1162 | 1100 | 952 | 938 | - |
| In 10 days | 896 | 872 | 841 | 787 | 49 |
| In 36 days | 1125 | 1138 | 1124 | 1086 | 71 |

1 Average rate of feed intake over 9 days around 20 kg liveweight
2 Predictions made at T = 22°C and B = 0.01395 per day

P2. The pigs on treatment AT, where L and H feeds were offered on alternate days, consumed consistently higher amounts of feed when they had access to L rather than H (Figure 3.5.1). The average rate of feed intake was 1099 g/d on L and 967 g/d on H; the difference of 132 (s.e. 67), although appreciable, was not significant ($p = 0.13$).

*Performance*

C2 The Feed Intake Model predicted that none of the four feeds used could provide the non-limiting conditions for the growth of these pigs throughout the experiment. Feed B was imbalanced for the early days of the experiment, therefore the animals could achieve their potential protein growth only by increasing their rate of feed intake and consequently achieving higher level of fatness than the desired. Feed H became limiting at the later stages because pigs could not achieve their desired levels of fatness at the temperatures used. However, a Gompertz analysis of the liveweight gain of pigs on H, from 12-30 kg liveweight, estimated a rate parameter B for the four animals of 0.01390 (s.e. 0.00050) per day which was not statistically different from the expected rate of 0.01395 (from Chapter I). The daily liveweight gains (mean $\pm$ s.e.) during the whole period were 542 (36), 699 (45), 787 (18) and 781 (42) g/d, and the feed conversion efficiencies 0.481 (0.016), 0.615 (0.008), 0.702 (0.015) and 0.718 (0.024) for the feeds L, A, B and H respectively. These results agree with the findings of the previous two experiments.

(b) **Choice-fed pigs**

P3-P4. Pigs that had experienced both feeds (in one way or another) were expected to select a diet in a directed manner (P3) and of a certain composition at a given degree of maturity (P4). Such pigs were those on T3, in both periods (I and II) and the pigs on T1 and T2 during Period II. The first proposition (P3) was tested by comparing the average prop.H of each of these treatments

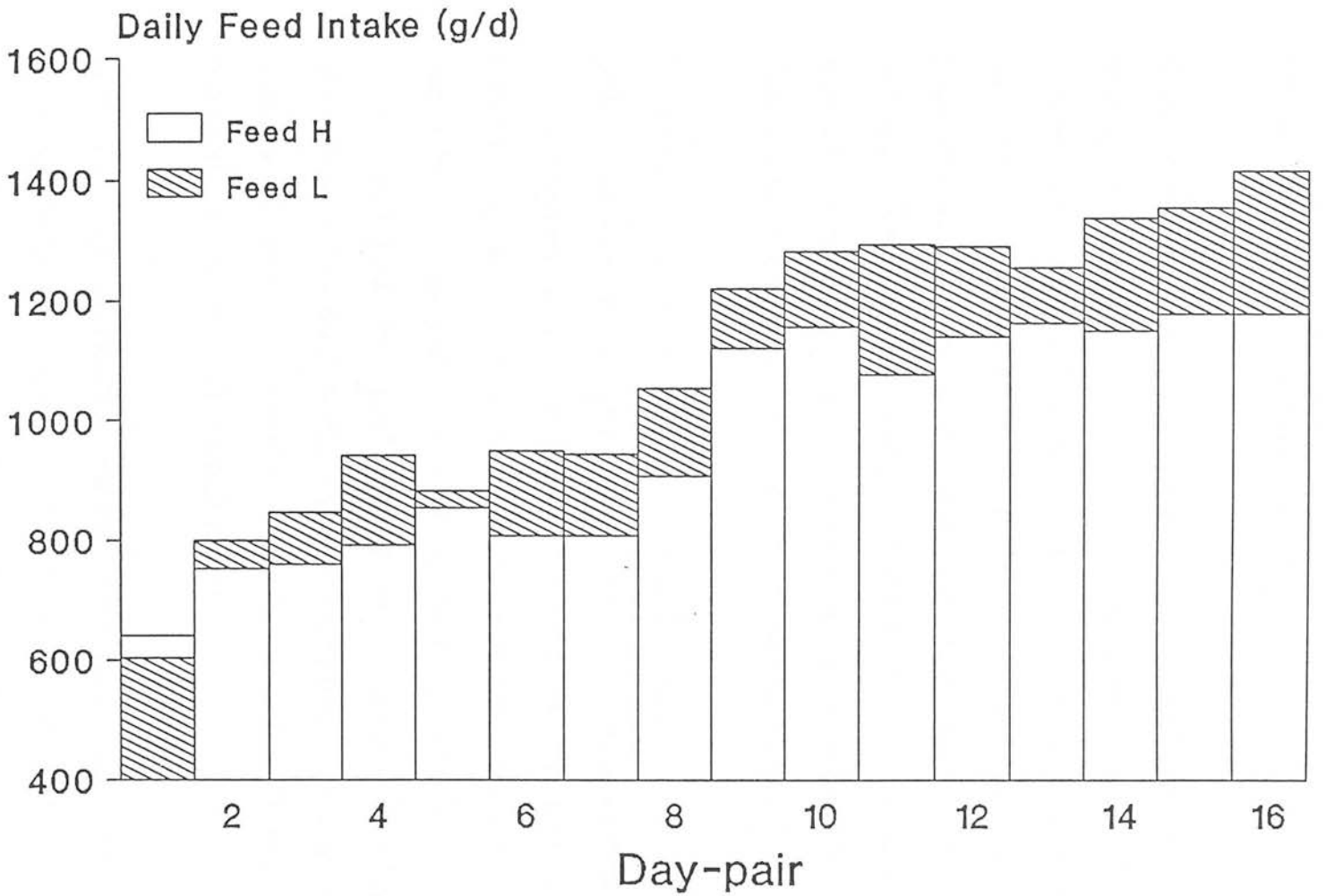


Figure 3.5.1 Daily intakes of feeds L and H, by pairs of days, for the pigs on treatment AT (L and H offered on alternate days).

against the null hypothesis (ie. prop.H = 500 g/kg TFI). The null hypothesis was rejected for the T3 pigs (in both periods) and for the T2 pigs in Period II ($p<0.05$). However, it could not be rejected for the T1 pigs in Period II, which selected a diet with a higher prop.H than T2 and T3 pigs, close to 50-50% composition (prop.H = 454 (s.e. 48) g/kg TFI).

Since the pigs on all the three treatments had similar liveweights at the beginning of Period II (around 27.5 kg) and assuming that their body composition did not differ substantially, they were then expected to choose diets of similar composition (P4). An analysis of variance carried out on the prop. H selected in Period II showed that there were no significant differences between the three treatments (Table 3.5.5). However, there were some differences in the prop.H selected during the first two days of Period II (Figure 3.5.2) which had some effect on the average prop.H selected.

In addition, the proposition (P4) was also supported by the summary of the paths of diet selection. In Figure 3.5.3 the plots of the cumulative difference in intake of feeds H and L against the cumulative total feed intake (H+L) have been used again to describe the essential characters of the paths of the diets selected by the pigs on treatment T3 (Period I). For five pigs the pathways of diet selection showed a distinct similarity: preference for feed H. The diet selected by the sixth pig (No. 20) differed from the average in its composition (a preference for feed L) for the first three days. Thereafter, it consumed a diet which contained a high prop.H.

P6. A formal test of the proposition that pigs on T4 would select a diet which would vary considerably among individuals in its composition (P6) , was to compare the average prop.H against the null hypothesis prop.H = 500 g/kg TFI; that is a choice made at random. However, this test was not strong

TABLE 3.5.5 The proportion of total intake as the higher protein feed prop.H (g/kg TFI) selected by the choice-fed pigs (treatments T1-T3) during Period I and II (means (s.d.))

| | Treatment | | | |
|---|---|---|---|---|
| | T1 | T2 | T3 | Effects |
| Period 1 | 472 (208) | 817 (88) | 723 (137) | T1 <T2, T3 |
| Period II | 454 (48) | 366 (94) | 409 (78) | n.s. |
| Effects of period | ns | ** | ** | |

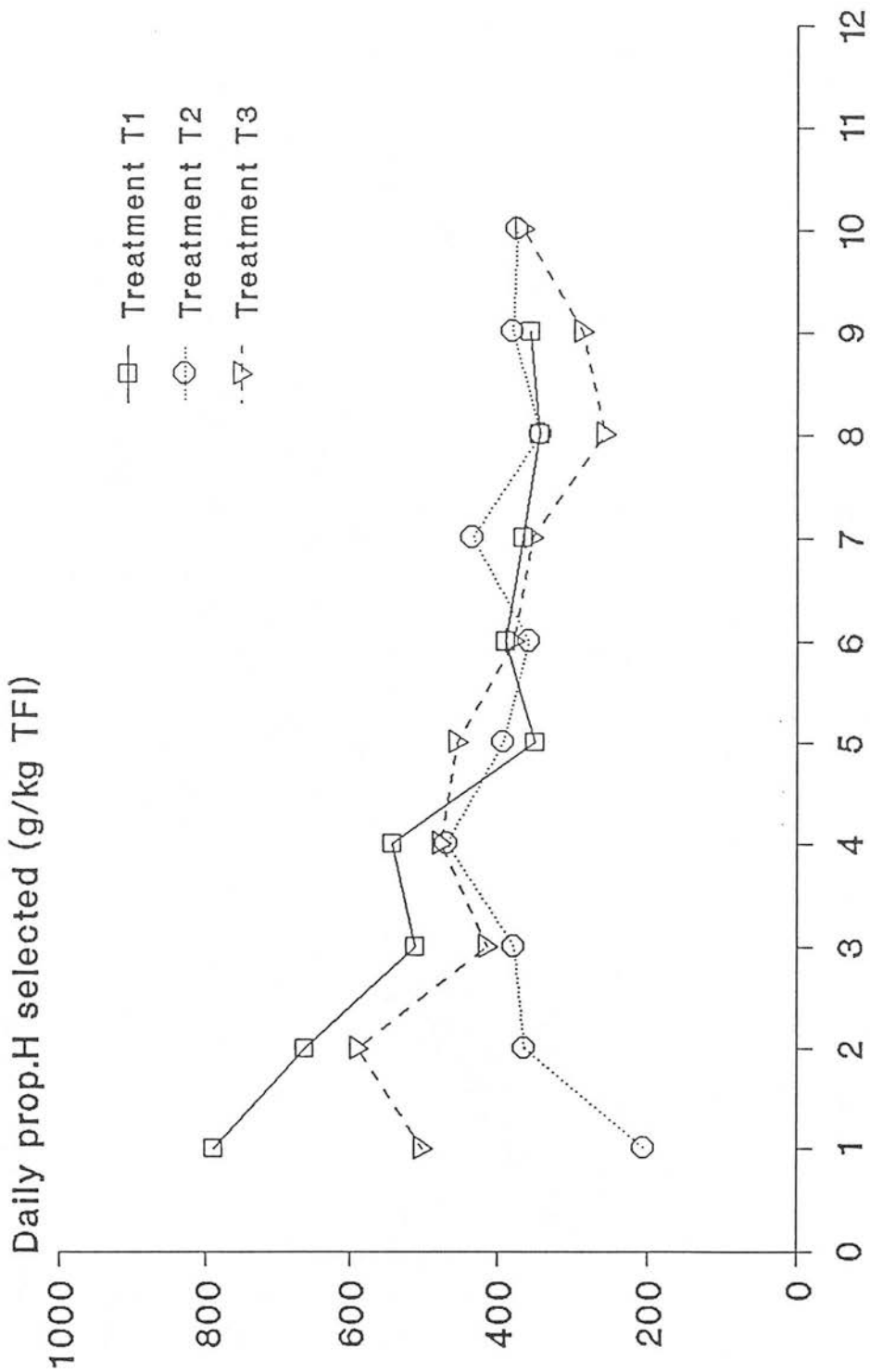


Figure 3.5.2 The daily prop. H (g/kg TFI) selected by the pigs on treatments, $T_1$, $T_2$ and $T_3$ during Period II.

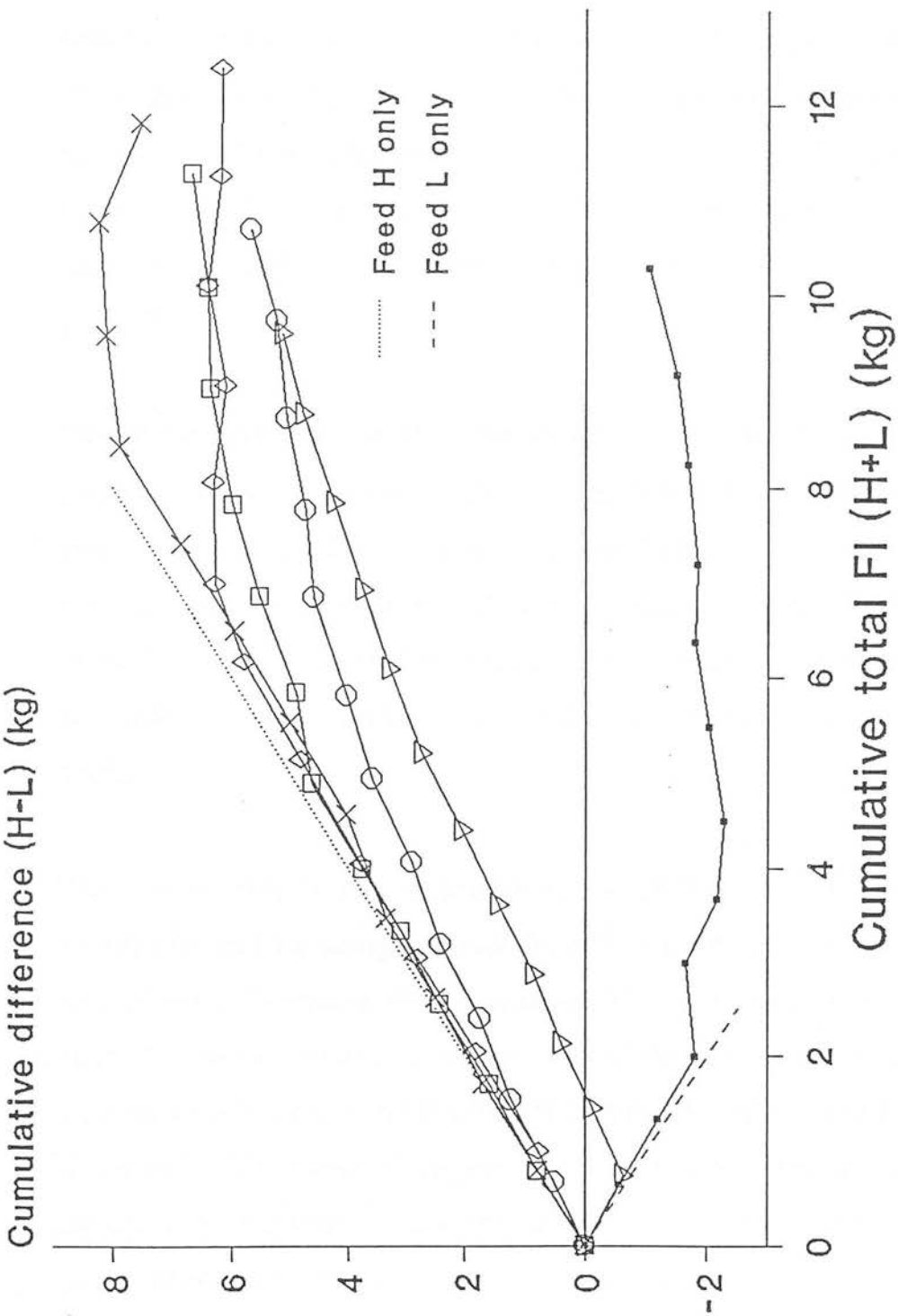


Figure 3.5.3 Paths of diet selection of pigs on treatment $T_3$ (Period I). Each line refers to an individual pig; the (■——■) refers to pig No. 20.

enough, since the average prop.H was not expected to be different from 500, even if pigs were to choose their diet in a directed manner (a fact which is substantiated by the diet selection of the T3 pigs). This weakness was overcome by dividing the 36 day period into two sub-periods. If the T4 pigs were to select their diet in a directed manner, then the prop.H would be above and below 500 g/kg TFI, for the first and second sub-period respectively. However, the average prop.H selected by pigs on T4 was 506 and 411 g/kg TFI, for the two sub-periods respectively and these proportions were not significantly different from each other nor from randomness (ie. 500 g/kg TFI).

When the individual paths of diet selection of the pigs on T4 were plotted in a similar way as for the pigs on T3, it can be seen that their paths varied considerably (Figure 3.5.4). Two pigs preferred feed L, one pig selected a diet in favour of feed H and three pigs selected a diet of 50-50% composition. This variation of the diets selected by the pigs in this treatment is contrasted with the small variation of the diet selection on T3 (Figure 3.5.3).

P5. The average values of prop. H selected by pigs on T3 in Period I and II, provided the data for testing the proposition that the CP content of the diet selected would decrease as the pigs matured (P5). A comparison of these values for the two periods, by a t-test, showed that the prop.H decreased significantly with time (from 723 g/kg TFI in Period I to 409 g/kg in Period II; $p<0.001$). The decline in the prop. H resulted in a decline in the CP content of the diet selected, from 223 (Period I) to 180 g CP/kg fresh food (Period II) ($p<0.001$). This decline in the prop. H and the CP content selected is best illustrated in Figure (3.5.5), where the cumulative difference in feed

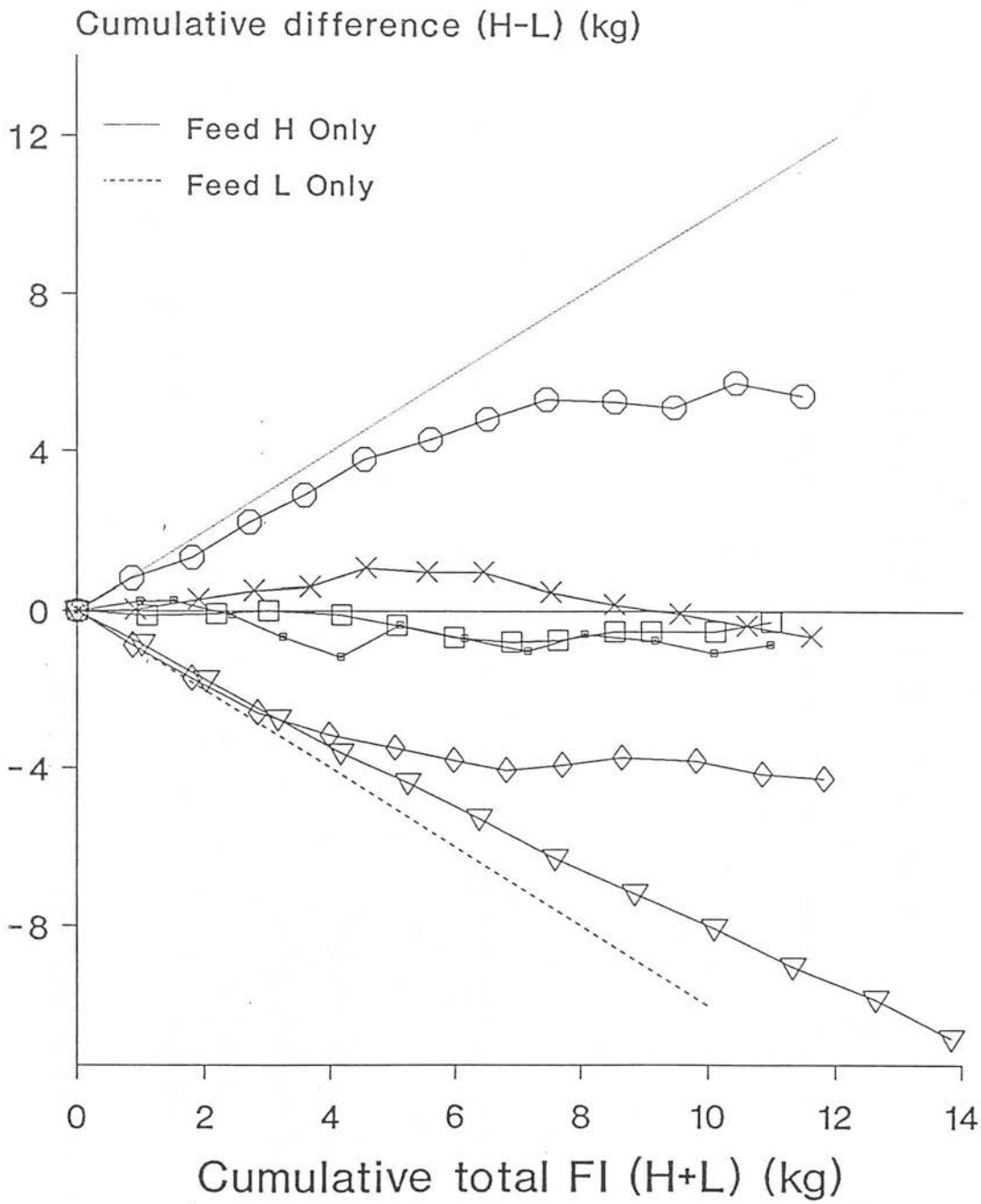


Figure 3.5.4 Paths of diet selection of pigs on treatment $T_4$ (Period I). Each line refers to an individual pig.

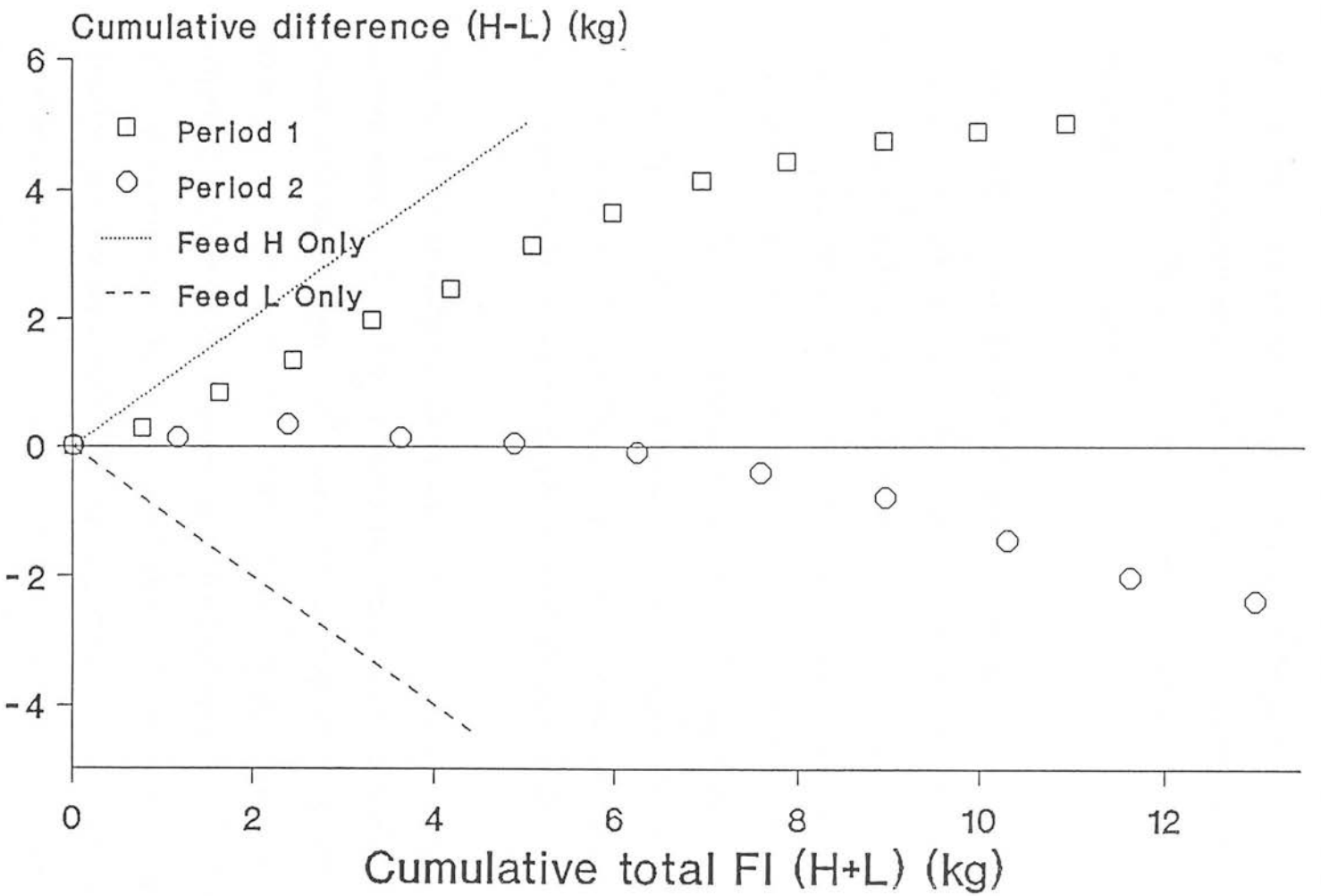


Figure 3.5.5 The average path of diet selection of pigs on treatment $T_3$ in Periods I and II.

intake was plotted against the cumulative total feed intake, for the two periods respectively.

C1-C2 As for the single-fed pigs, the model predicted that the pigs were not able to achieve their potential growth, at the later stages of Period II. This was due to the house temperatures used in the experiment. Therefore, the corollaries (C1-C2) could apply only for the choice-feeding part of Period I, but not for the similar part of Period II.

Pigs that had experienced both feeds at the beginning of Period I and then given a choice between L and H (treatment T3 - Period I) had a rate of total feed intake, at 18 kg liveweight, of 888 (s.e. 32) g/d which was not different from the prediction of the Feed Intake Model. The rate of total feed intake was the average of 7 days, and the predictions were made at a house temperature of $22^{0}$C. A Gompertz analysis of the liveweight gain of these pigs during the 12-day period estimated a rate parameter B of 0.0135 per day (0.0004) which was not significantly different from the expected value 0.01395 per day for pigs growing at their potential rate (Chapter I).

Pigs that had experienced both feeds and were then given a choice in Period II (treatments T1, T2 and T3 - Period II) had similar rates of total feed intake at 33 kg liveweight, which were 1316 (s.e. 63), 1394 (s.e. 172) and 1364 (s.e. 63) g/d respectively. These values, though lower, were not significantly different from the prediction of the Feed Intake Model of 1478 g/d. The growth rates of the choice-fed pigs in Period II could not be described by a Gompertz analysis for the reasons given earlier. The daily liveweight gains of these pigs during the 10 day period were 800 (s.e. 34), 774 (s.e. 31) and 838 (s.e. 54) g/d, for the treatments T1, T2 and T3 respectively (no significant difference between treatments).

### 3.6.4 Discussion

#### (i) Single-fed pigs

The observed feed intakes were consistent with those reported in Experiments 1 and 2, and with the predictions of the model. The animals increased the rate of feed intake at a weight (eg. 20 kg liveweight) as the protein content of the feed was decreased. This increase was also evident when the actual rate of feed intake was calculated for a short period of time (ie. 10 days), but it was not seen up to the 36 days on the experiment. This was attributed to the different growth rates achieved on each treatment; pigs on the low protein feeds (L or A), grew more slowly than pigs on feeds B or H. Since the heat loss, and consequently the rate of feed intake, are functions of liveweight, animals on the low protein feeds had a reduced total feed intake due to smaller body weights. This reduction in the total feed intake on low protein feeds, almost exactly offset the direct effect of feed protein content at a liveweight. If the experiment had continued beyond 36 days, the difference in total feed intakes would have become greater, with the pigs on L being much smaller and, consequently, consuming less than B or H pigs.

Similar results have been observed in experiments by Wethli, Morris and Shresta (1975) and Freeman (1979), where feed intake was recorded on a time-scale basis. In Freeman's (1979) experiment, young chicks were given access to feeds with different protein (and tryptophan) contents and the data were recorded on a weekly basis. During the first week of experimentation, chicks on the low protein feed consumed 1.07 times the rate of the feed intake of animals on the high protein feed. After seven weeks of experimentation, this effect on the rate of feed intake was reversed, with chicks on the high protein feed eating and weighing more than the chicks on the low protein feed.

Whether the effect of feed protein content on the rate of feed intake is measured at a weight or over a fixed time can explain the common confusion on the direction of this influence (Harper and Boyle, 1976). Models which predict the rate of feed intake over a period of time (eg. Mercer and Dodds, 1985) often have ignored the effect of liveweight on feed intake, and therefore have misleadingly suggested that feed intake is depressed when the feed protein content is low.

The results from the AT treatment, where animals were offered the L and H feeds on alternate days, give support for a short term regulation of protein intake. Although there are apparently no comparable experiments, it has been suggested that rats are able to detect changes in the protein content of their feeds within four hours (Harper, 1967). A similar situation may apply to chickens (Chah and Moran, 1985) where it has been suggested that they are able to regulate their protein intake on a 12-hour basis. A closer examination of the diurnal rhythms of feed intake could give the relevant evidence on the short term regulation of protein intake. The idea that pigs are able to regulate their protein intake on a short-term basis, will be discussed in more detail in Chapter IV.

**(ii) Choice-fed pigs**

All three methods (T1-T3) of ensuring that animals had sampled both feeds that were subsequently given as a choice, resulted in similar diets being selected by the pigs in Period II. Pigs that had experienced both feeds (treatments T1, T2, T3 in Period II and treatment T3 in Period I) chose between the two feeds on offer in a directed manner and the composition of the diets selected did not vary much between individual pigs. These results give strong support to the idea that animals first need to learn about the feeds if they are to make successful choices. However, the small differences in the average prop.H selected between the three treatments in Period II, reflecting mainly the different prop.H selected during the first couple of days of Period II, need to be discussed.

Pigs on T1 (experience on feed L only during the first six days of Period II) showed a marked preference for feed H (prop.H selected was around 800 g/kg TFI) for the first three days. Subsequently their prop.H was similar to that selected by pigs on T3 (Figure 3.5.2). In an analogous way, animals on T2 (experience on feed H only during the first six days of Period II) selected initially a diet in favour of feed L (prop.H around 200 g/kg TFI) and then selected a similar diet to the pigs on T3. The first hypothesis which can account for such behaviour is along the lines of the feed aversion paradigm (Rozin, 1969). In these terms pigs, given access to one feed only, will avoid the feed abundant in nutrients (ie. feed H) or the deficient feed (feed L) as soon as the second feed (L or H respectively) is introduced, as a choice. However, this hypothesis cannot explain why animals previously given access to feed H (treatment T2) still consumed substantial amounts of this feed when they were offered a choice between L and H, or why pigs on both T1 and T2 very rapidly changed their selected diet composition to be similar to that of the pigs on T3.

An alternative hypothesis could be that the previous feeding of the animals affected significantly their subsequent diet selection. Such a hypothesis suggests that animals fed on an imbalanced feed were diverted from their desired body composition, and therefore when subsequently given a choice between two appropriate feeds, selected a diet that enabled them to restore their body composition. This hypothesis could then account for the minor deviations of pigs on T1 and T2 from the diet selected by pigs on T3. The idea that an animal selects a diet in order to restore its body composition to that desired will be dealt with in detail in Chapter IV.

The behaviour and the diet selected of the animals on T1 and T4 in Period I is similar to that observed in Experiments 1 and 2. The diets selected varied considerably among the individuals of each treatment and there were, therefore, only some pigs which made correct dietary choices and consequently grew at their

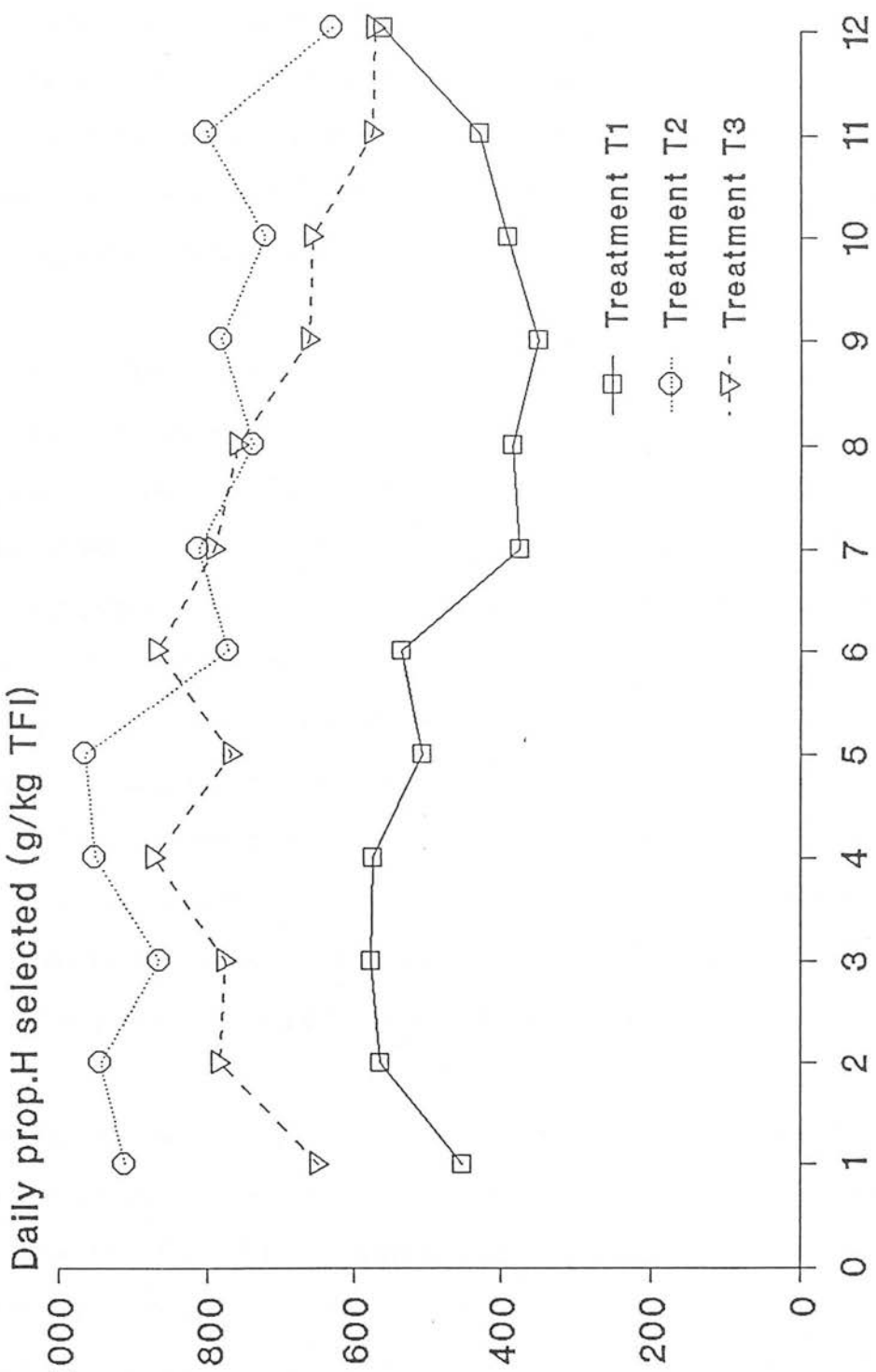


Figure 3.5.6 The daily prop. H (g/kg TFI) selected by the pigs on treatments $T_1$, $T_2$ and $T_3$ during Period I.

assumed potential. However, the diets selected by the individuals on T2 (Period I) did not vary much and all the animals on this treatment were successful in their diet selection. This fact must be considered accidental (that none of the four pigs was inhibited, by its eliminative behaviour, to sample both feeds when they were offered as a choice) and not as evidence that such a method could help pigs to be successful in their diet selection. In addition, the diet selection of the pigs on T2 (a higher prop.H than that of pigs on T3) can be explained by the hypothesis that previous feeding regimes influence subsequent diet selection (Figure 3.5.6).

It has often been suggested that the outcome of choice-feeding experiments depends on the simple preference of the individuals (Scott and Quint, 1946) or that many animals are needed to overcome the considerable variation and demonstrate success (the success being measured by the rapid growth of the group as a whole, and not of the individual) (Dove, 1935). The experiment reported here suggests that the problem may well be able to be overcome, by allowing the animals to sample the feeds on offer. Successful results can then be obtained with a small number of animals. Therefore, the most successful of the experience methods established in this methodology experiment, ie. the six-day period with alternating feeding, will be used in the subsequent experiments of this thesis. However, it must be stressed that other, probably better, methods of experience may well exist, but an extensive investigation into this is beyond the objectives of this thesis.

Finally, it is also proposed that the path of diet selection of every pig lies on a universal curve of a form common to that of pigs in treatment T3, but which differs in magnitude for individuals according to their unique requirements for energy relative to protein (eg. female pig No. 20, Figure 3.5.3). Consequently, a degree of variation may have to be tolerated in both the dimensions of diet composition (Cumulative Difference in feed intake (H-L)) and the total feed intake in experiments of this kind, as the individual seeks to express its unique potential.

## 3.7 EXPERIMENT 4: A COMPREHENSIVE INVESTIGATION INTO THE RULES OF DIET SELECTION

### 3.7.1 Objectives

The results of the previous experiment, considered together with these of the first two, suggested that pigs which experienced separately the two feeds on offer, could make correct dietary choices. However, the questions addressed and the design of Experiment 3, did not permit a detailed investigation into the rules of diet selection to be carried out. The only two ideas tested in Experiment 3 and which appeared to hold were:

(i) pigs selected a diet of a certain composition, according to the protein content of the feeds on offer, and

(ii) the protein content of the diet selected decreased as pigs matured.

Experiment 4 was conducted to test more severely the theory of diet selection. It was earlier suggested (Section 2.6) that when two feeds, which differ only in their crude protein:energy ratio, are given as a choice, there are three kinds of pairs to be considered:

(a) a limiting and an abundant feed

(b) two abundant feeds

(c) two limiting feeds

A good design to investigate the rules of diet selection is then to have four feeds, of which two are above and two below the animal's requirement. The complete design will comprise ten treatments, that is: the four feeds given singly, as control treatments and the four feeds given as the six possible two-way choices.

The elected approach to the problem included similar pigs and feeds, and had the same outline as treatment $T_3$ (Period I) in the previous experiment. That is, pigs were given a six-day period of experience on the two feeds separately, on alternate days, before they were offered both feeds as a choice. The additional advantage of this strategy was that some of the outcomes of Experiment 3 (mainly the ones concerning the composition of the diet selected) could be used as a basis for firmer expectations in this experiment.

Therefore, the fundamental propositions of the theory of diet selection, which were addressed back in Experiment 1, and failed to survive the test of that experiment, were asserted once again.

### 3.7.2 Propositions

The experiment was designed to test the following propositions:

P1 Pigs will choose between the feeds on offer in a directed (non-random) manner.

P2 Pigs, given the opportunity, will select a diet of a certain protein composition, according to the protein contents of the feeds on offer.

P3 The protein content of the diet selected will decrease as the pigs mature and it will be different between the sexes (higher in the males than the females).

P4 Pigs will not select their diet on the basis of the position of the feeds.

P5 Pigs will minimise their excess nutrient (protein) intake.

P6 Pigs given a choice between two limiting feeds will eat only the least limiting one.

#### 3.7.2.1 Corollaries

Should pigs, given the opportunity, select a common diet, their growth will not be first limited by nutrient, in which case:

C1 The pigs will have a similar rate of total feed intake at a weight, which will be that predicted by the Feed Intake Model (Chapter II).

C2 These pigs will grow at a rate set by their inheritance and have a similar Gompertz liveweight gain parameter, expected to be (from Experiment 3) 0.01350 per day.

C3 Pigs given a choice between two limiting feeds will have a rate of total feed intake, at a weight, above that of pigs given a choice between two feeds, a combination of which is non-limiting to growth, in order to attain their desired intake of protein.

### 3.7.3 Materials and Methods

The housing and management procedures were, in general, those described in Experiments 1, 2 and 3. Any changes in the routine are described below.

*Animals*. Forty Cotswold Large White x Landrace pigs (20 entire males and 20 females) from 7 litters, were individually caged in the controlled environment portacabin used for the previous experiments. The animals were moved immediately after weaning (at 4 weeks of age) and had not been offered any supplementary feed prior to weaning.

*Feeds*. Two basal feed (L and H) with identical formulations as feeds L and H in Experiment 3, and their two-step mixtures (feeds A and B) were made into pellets (Table 3.5.1). The estimated analysis of the four feeds is given in Table 3.6.1. The estimated, by the analysis, CP values (N x 6.25) were regressed on the proportion of feed H they contained (0, 0.33, 0.67 or 1 respectively). The regression equation derived was:

Feed CP content = 125 + 139 (s.e.5.2) x prop. H g/kg of fresh feed ($r^2$ = 0.997).

**TABLE 3.6.1 The chemical analysis of the four feeds (g/kg fresh weight) used in Experiment 4**

| Component (g/kg) | FEED | | | |
|---|---|---|---|---|
| | L | A (2/3L+1/3H) | B (1/3L+2/3H) | H |
| Digestible energy[a] (MJ/kg) | 15.8 | 16.3 | 16.7 | 17.1 |
| Dry Matter | 904 | 903 | 911 | 895 |
| Crude Protein (CP) | 125 | 174 | 213 | 267 |
| Ether Extract | 82 | 83 | 90 | 92 |
| Ash | 58 | 64 | 77 | 85 |
| Fibre (NDF) | 43 | 33 | 38 | 42 |
| Gross Energy (MJ/kg) | 16.7 | 16.9 | 17.2 | 16.2 |

a values calculated from feed tables

The CP values were recalculated by the above equation and the calculated values were then used as corrected CP content of the four feeds, for the analysis of the results.

**Methods**

*Pre-experimental period*. The pigs had a mean liveweight of 7.46 (s.d. 0.87) kg when they were moved into the cages. The pre-experimental period ended when animals reached the 12 kg liveweight and lasted for 14 days (s.d. 3 days) on average. None of the animals died or had to be replaced during this period.

*Experimental Design*. The design was a complete two-way choice feeding experiment, using four feeds. This resulted in ten treatments, which were the four feeds fed single (treatments L, A, B and H) and the four feeds as two-way choice (six possible pairs, treatments LA, LB, LH, AB, AH and BH). Each treatment had two animals from each sex; the animals were allocated randomly to the treatments taking account of age at 12 kg and with a restriction for litter origin. The experiment ended when animals reached 30 kg liveweight.

The choice-fed animals were given the opportunity to experience separately the two feeds which subsequently were given as a choice. The two feeds were offered alone on alternate days, for a period of 6 days (according to the method used in Experiment 3). The position of the feeds did not change throughout the experiment (the experience period included), but the position of the feeds was randomised across pigs. To test the proposition that choice-fed pigs will not select their diet on the basis of the position of the feeds, the position was reversed at the end of the experiment (30 kg liveweight) and feed intake recording continued for an additional week.

*Management*. The animals were weighed daily and fed twice a day (morning and afternoon) to minimise the spillage, which was low, measured, and allowed for. The weighing procedure started at 9 am and followed the same animal sequence every day. The feeding routine began immediately after weighing and also followed the same animal sequence. Feed refusals were weighed daily and discarded; for wet refusals, the dry matter was measured.

The experiment took place during the summer of 1987 (May-July) and the temperature aimed for in the main part of the experiment was 21-22$^{o}$C.

### 3.7.4 Results

#### (a) Single-fed Pigs

The rate of feed intake at a weight decreased as the protein content of the feeds was increased from L to H. The rates of feed intake at 20 kg liveweight (the values represent the average of 9 days) were 1142 (s.e. 80), 1061 (s.e. 56), 1018 (s.e. 40) and 878 (s.e. 49) g per day, for feeds L, A, B and H respectively. The above values were not significantly different from the predictions of the Feed Intake Model made for pigs at 20 kg liveweight and at 22$^{o}$C ambient temperature, which were: 1163, 1098, 951 and 939 g per day for the four feeds respectively.

The Feed Intake Model also predicted that only feed H could provide the non-limiting conditions for the growth of these pigs, from 12-30 kg liveweight. Feed B was limiting for the early stages of the experiment, but then became non-limiting. A Gompertz analysis of the liveweight gain of the pigs on H (the mature protein weights, $P_m$, were taken to be 45 kg for the males and 40 kg for the females; Chapter I) estimated a growth rate parameter B for the four animals of 0.01252 (s.e. 0.0005) per day which, although lower, was not significantly different from the expected value of 0.01350 (s.e. 0.0004) per day, from Experiment 3.

The effects of treatment (level of crude protein in the feed) on the average rate of feed intake, daily rate of liveweight gain and feed conversion efficiency (FCE) (g/ gain/g feed) are shown in Table 3.6.2. The table shows that the pigs on B and H had similar rates of liveweight gain and that the FCE declined as the crude protein content of the feed was reduced; although not measured an increase in the lipid content of the liveweight gain is therefore indicated. The effect of sex and sex x treatment were inappreciable and non-significant.

(b) **Choice-fed pigs**

Pigs on each treatment had different average liveweights when they were first given access to both feeds as a choice, as the result of the different feeds offered during the six-day experience period. Pigs on the LB, LH, AB and AH feed pairs had a similar average liveweight which was 15.08 (s.e. 0.14) kg. However, pigs on pair LA were slightly lighter, 14.36 (s.e. 0.16) kg and on BH were heavier 16.47 (s.e. 0.19) kg, than the above. These differences in liveweight at the start of the choice-feeding period, were taken into account when diet selection was considered later in the discussion.

P1 The diets selected by the pigs on the six diet pairs are given in the first column of Table 3.6.3, where it can be seen that there was not a complete avoidance of any of the four feeds across treatments. The most obvious statistical test of the proposition that the diet was selected in a directed manner (P1), was to compare the proportion of the total feed intake (TFI) which was taken from the trough containing the lower protein feed (feed 1, Table 3.6.3) in each treatment against the null hypothesis: proportion feed 1 = 500 g/kg TFI; that is a choice made at random. However, from the set-up of the experimental design, some treatments were expected to have an average proportion feed 1 (prop. 1) selected around 500 g/kg TFI (ie. pair LH). Therefore, this test would be unhelpful for these pairs since a failure to show

**TABLE 3.6.2 Effects of treatment (level of crude protein in the feed) on average rate of feed intake, daily rate of liveweight gain and FCE of pigs, from 12-30 kg liveweight (mean (s.e.))**

| | Feed | | | |
|---|---|---|---|---|
| | L | A | B | H |
| CP content (g/kg fresh feed) | 125 | 174 | 213 | 267 |
| Feed intake (g/d) | 1001 (48) | 971 (48) | 961 (36) | 868 (44) |
| Liveweight gain (g/d) | 492 (33) | 627 (20) | 743 (20) | 693 (25) |
| FCE (g of gain/g of feed) | 0.491 (0.015) | 0.648 (0.025) | 0.775 (0.025) | 0.802 (0.031) |

TABLE 3.6.3 The diets selected by choice-fed pigs: the proportion of the feed intake taken from the trough which contained feed 1 and the proportion of feed H and crude protein in the selected diets.

| Feed | | Proportion of total intake as Feed 1 (prop. 1 g/kg TFI) | | Proportion of H in selected diet (prop. H g/kg TFI)[a] | CP selected (g/kg fresh feed) |
|---|---|---|---|---|---|
| 1 | 2 | Mean | s.e. | | |
| L | A | 290 | 200 | (237) | (160) |
| L | B | 64 | 35 | 624 | 208 |
| L | H | 445 | 56 | 555 | 204 |
| A | B | 309 | 214 | 564 | 202 |
| A | H | 665 | 123 | 557 | 205 |
| B | H | 982 | 4 | (655) | (218) |
| s.e.d. | | 182 | - | 93[b] | 11[b] |

a calculated from diets selected where L, A, B and H contained 0, 1/3, 2/3 and 1 as H
b excluding treatments LA and BH

any significant difference from the null hypothesis would not necessarily mean that the animals on these treatments selected at random. On the other hand, such a test was helpful for other treatments (ie. pairs LB and BH) where the prop. 1 was different from 500 g/kg TFI ($p<0.001$).

The best way then, of describing the directed manner of diet selection was to relate the proportion of TFI chosen as one feed to that of the three others and this is displayed in Figure 3.6.1. It can be seen in this figure that the proportion chosen as one feed (L, A, B or H) varied systematically with the other feed given. For example, the proportions of TFI which were eaten from the trough containing feed H (prop H) were 555, 335 and 17 g/kg TFI, when the other feed was L, A and B respectively; this decline was highly significant ($p<0.001$).

The variation in the diets selected between individual pigs on a treatment was very small for the majority of the feed pairs (ie. pairs LB, LH, AH and BH). However, the variation increased and was appreciable in the treatments where the animals had a choice between two feeds not very different from each other (as were pairs LA and AB) (Table 3.6.3). For the treatment AB the variation was attributed to one animal which preferred feed A (prop A for this pig was 924 g/kg TFI), whereas the three others showed a preference for feed B (average prop. A for the three pigs was only 104 (s.e. 86) g/kg TFI).

P2 Since each of the four feeds included different proportions of feed H when they were mixed, it was possible to calculate the proportion of the total feed intake as feed H (proportion as feed H or prop. H). The third column of Table 3.6.3 shows the corresponding treatment means calculated from the data of individual pigs. However, this calculation could be misleading for the two extreme pairs (LA and BH), since pigs on these pairs could select only within

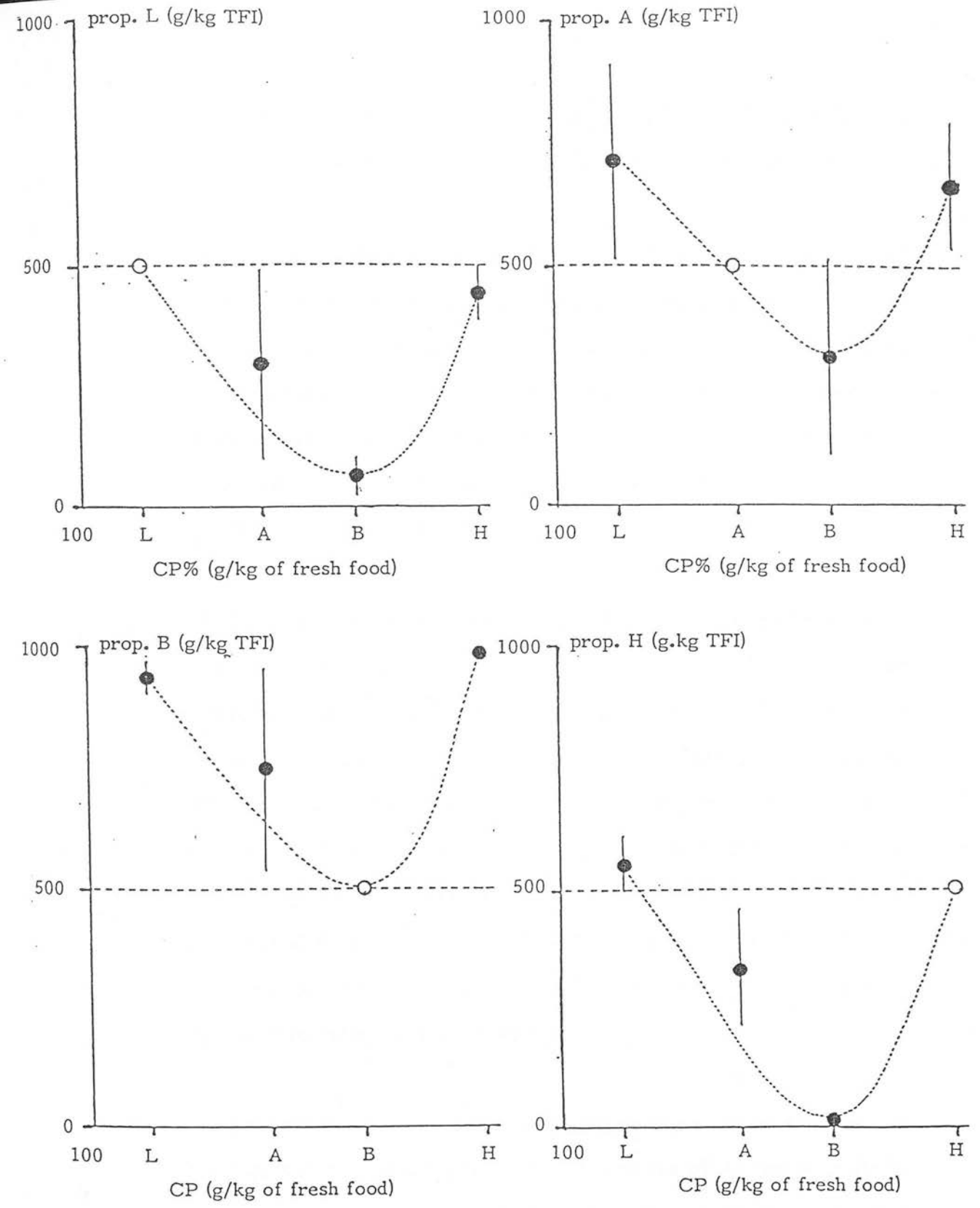


Figure 3.6.1 The effect of treatment on the composition of the diet selected by pigs (• mean ± 1 s.e.). The dotted line indicates the level of random selection (500 g/kg TFI). The symbol ○ shows an equal choice where the two feeds offered are the same. The curves are drawn through the points by eye.

the ranges 0-333 and 666-1000 g/kg of TFI of prop. H in their diets respectively. For this reason, these two pairs were considered separately.

The prop. H data was then used to test the proposition that all pigs will select a diet of a certain composition, that is, prop. H will be constant across the four treatments (P2). An analysis of variance showed no significant treatment effects on the prop. H ($p>0.20$). Proposition 2 therefore withstood the test of the data, and it may be seen that the pigs selected a common diet with an overall mean prop. H of 575 (s.e. 29) g/kg TFI. This resulted in the selection of a similar CP level in their diets (204 (s.e. 3.8) g/kg of fresh feed).

P3 The decline in the protein content of the diet selected as the pigs matured, if present, was expected to be best seen in the pairs where the animals were able to meet their requirements throughout the experimental period (ie. pairs LH and AH). When the individual paths of diet selection of the four pigs on the LH pair are plotted (Figure 3.6.2), it could be seen that their prop. H selected declined over time. For three pigs it declined from around 700 g/kg TFI during the first week, to 500 g/kg TFI during the rest of the experimental period (remaining 11 days). For the fourth pig it declined from 600 to 300 g/kg TFI respectively. The decline was statistically significant for all the four pigs ($p<0.05$).

The expected difference in the diets selected by males and females, on pairs LB, LH, AB, AH, were not observed, although the differences were in the expected direction. Male pigs selected a higher prop. H (610 g/kg TFI) than females (539 g/kg TFI) (s.e.d. 66; non significant); this resulted in the selection of a diet with a higher crude protein content by the males (209 g CP/kg fresh feed), than females (200 g CP/kg fresh feed) (s.e.d. 9; non significant).

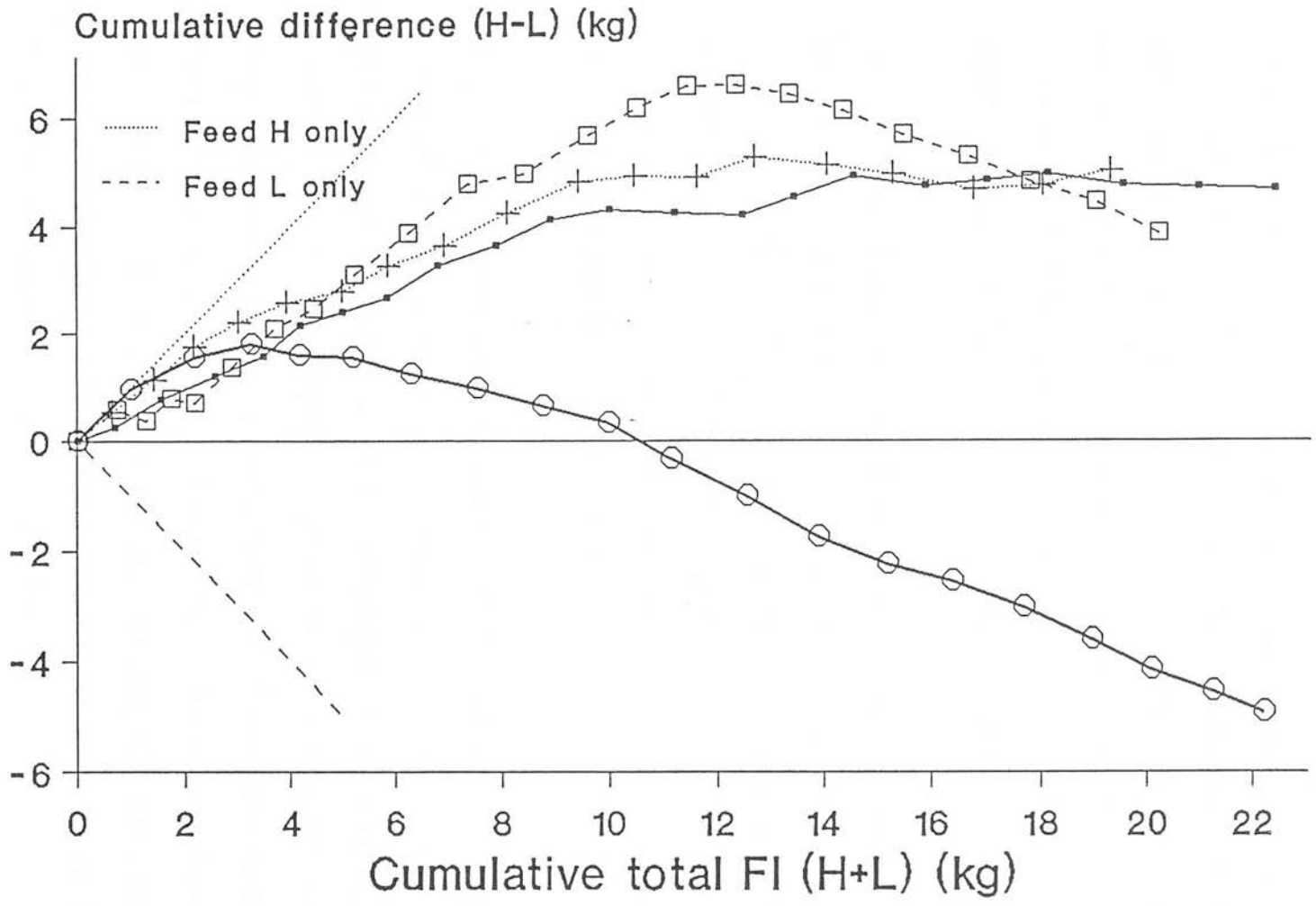


Figure 3.6.2 The paths of diet selection of pigs given a choice between the feeds L and H. Each line refers to an individual pig.

P4 The data used for testing proposition (P4) that pigs will not select their diet on the basis of the position of the feeds, were the prop. X values (where X is the feed with the lower CP content in each pair) recorded for the day preceding the switching of the troughs and the prop. X values for the day following the change. The t-test of comparing the diets selection on the day before and the day after the changeover, showed that their difference was not distinguishable from 0 ($p>0.25$). However, this test was not sensitive enough to account for individual responses (as was discussed in the results section of Experiment 1) and the form of visual appraisal was again adopted.

When the prop. X (day after) was plotted against the prop. X (day before), there was a variation in the individual responses (Figure 3.6.3) with the majority of the pigs (11 out of 15) following the feed. This variation was considerably reduced when the prop. X was considered a week after and a week before the change (Figure 3.6.4). In this case only one animal appeared to select its diet on the basis of the feed position.

The above, together with the observation that the effect of the change of the position of the troughs diminished very quickly, could also be seen when the prop. X selected on each of the days of the week after the switching of the troughs was regressed on the prop. X selected the week before. The error mean square decreased and the correlation coefficient ($r^2$) increased over time (from $r^2 = 0.754$ for the first day to $r^2 = 0.908$ for the seventh day following the change). The correlation coefficient, however, did not change significantly after the third day following the change ($r^2$ values for the last four days were 0.874, 0.891, 0.902 and 0.908 respectively).

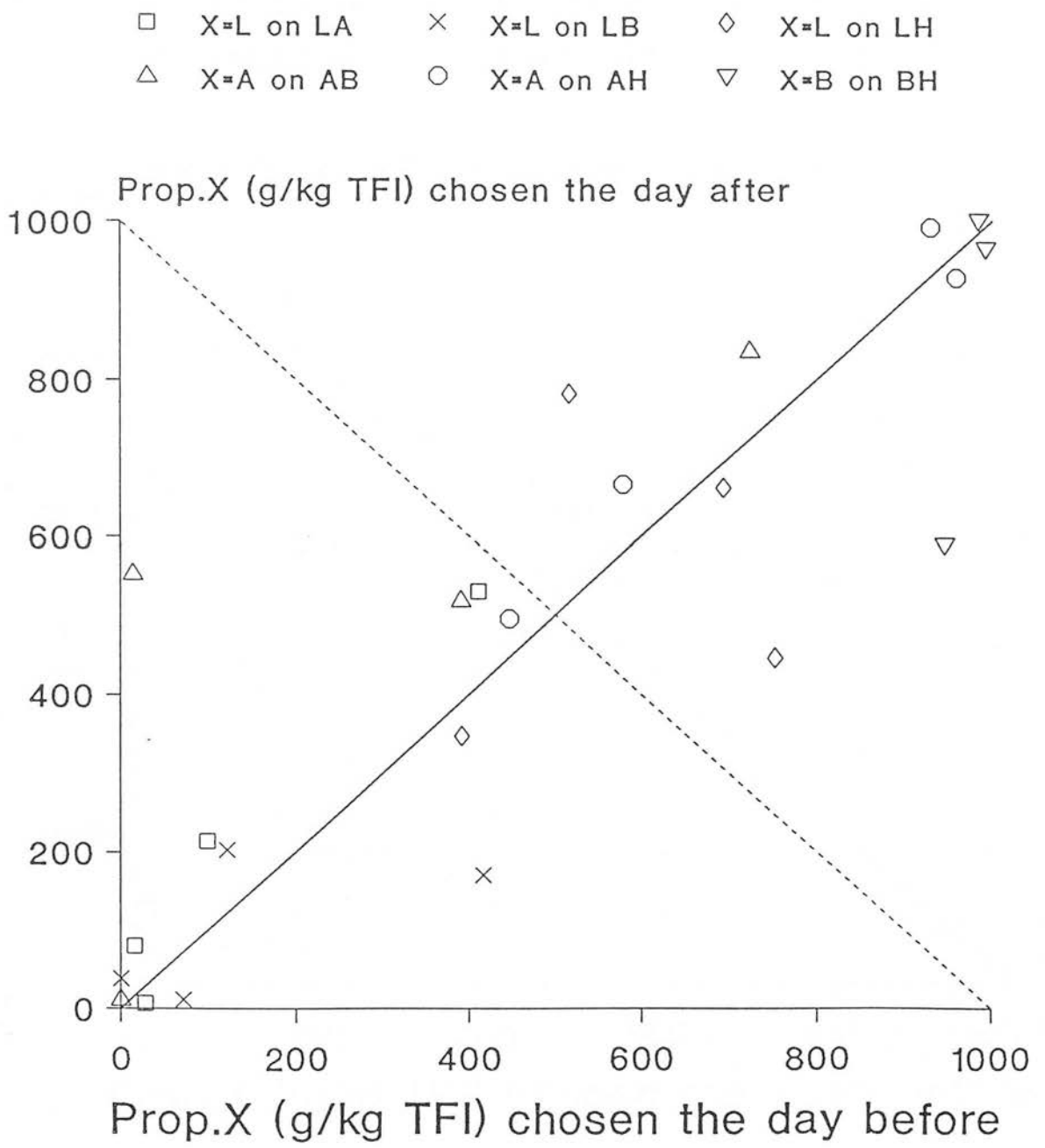


Figure 3.6.3 Effect of change in the position of the feeds on diet selection.

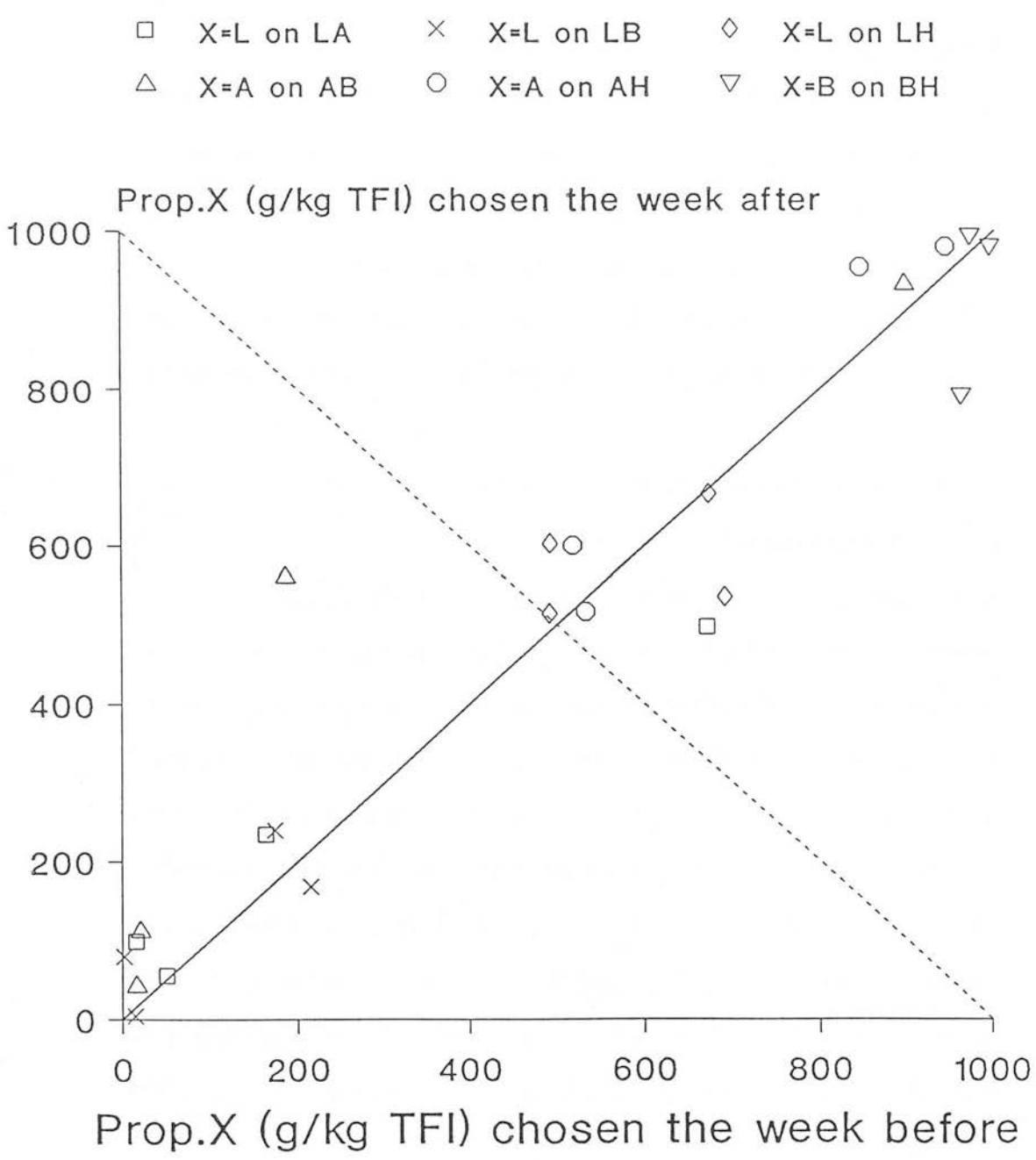


Figure 3.6.4 Effect of change in the position of the feeds on diet selection.

P5 The fact that pigs on the four pairs (LB, LH, AB and AH) selected diets with similar composition, gave indirect evidence that animals were avoiding, to some extent at least, an excess of protein intake (Proposition 5). A stronger test of this proposition was provided however by the BH pair, where pigs had a choice between a feed close to their CP requirements, B, and one abundant in CP, H. The expectation was that pigs would avoid feed H completely, that is prop. H = 0 g/kg TFI, only if feed B was adequate throughout. The prop. H selected had to be transformed (angular transformation) and the transformed values were found to be different from the expected outcome ($p<0.01$), indicating that pigs were consuming some of feed H. This amount was, however, very small (average prop. H = 18 (s.e. 3) g/kg TFI) and represented an average intake of only 29 (s.e. 20) g per day of feed H.

P6 Pigs given a choice between two limiting feeds were expected to eat only the less limiting one (Proposition 6). Therefore, the expectation asserted was that prop. L = 0 g/kg TFI for the pigs on the LA pair. Although the prop. L was not found to be significantly different from this expectation, this was due to the very large variation of the diets selected by the four pigs on pair LA. Three out of the four pigs preferred feed A, but they also consumed some amounts of feed L (prop. A was 903 (s.e. 71) g/kg TFI). The fourth animal preferred the more deficient feed L for the first half of the experiment and then it reverted to a 50-50 per cent choice. The paths of diet selection of the four animals on this pair are given in Figure 3.6.5. When all the four animals were considered together their prop. L (290 (s.e. 200) g/kg TFI) was not different from random choice either, due to this large variation in the diets selected.

C1 The average daily rate of total feed intake, daily rate of liveweight gain and feed conversion efficiencies of pigs given a choice between two feeds are

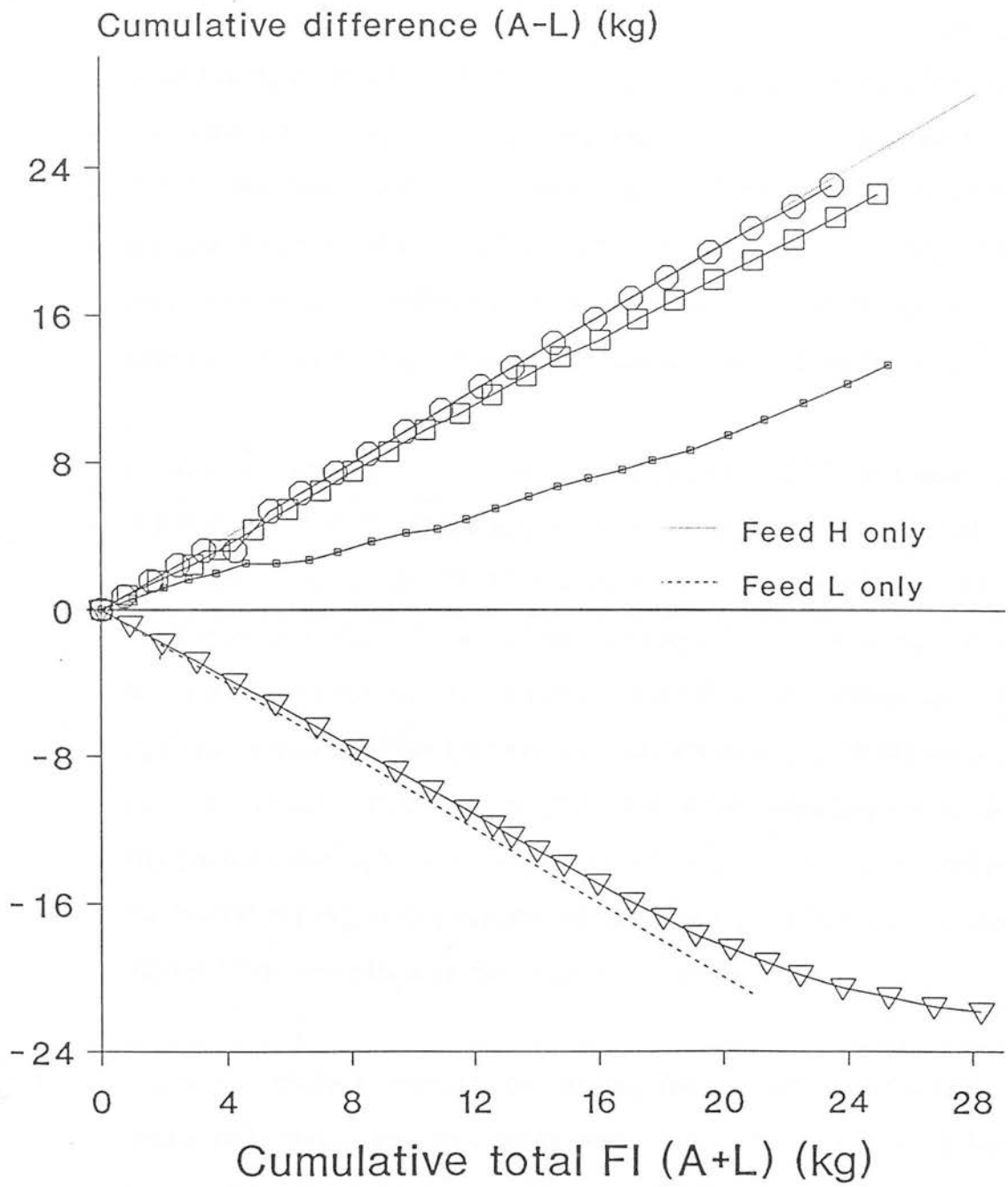


Figure 3.6.5 The paths of diet selection of pigs given a choice between feeds L and A. Each line refers to an individual pig.

summarised in Table 3.6.4. An analysis of variance in the daily rate of total feed intake indicated no significant differences between the four treatments: LB, LH, AB and AH ($p>0.20$), which result was not different from the expected corollary (C1). Female pigs on these four pairs had a higher rate of total feed intake than male pigs (1092 vs 994 g/d respectively), a difference of 98 (s.e. 42.9) g/d which just failed to meet significance ($0.1< p<0.05$); the interaction between sex x feed pair being inappreciable. The plot of the daily rate of total feed intake, at a weight, for the sixteen pigs (Figure 3.6.6) indicated that the rate of total feed intake did not differ significantly from the predictions of the model, with the exception of the rate of intake at 30 kg liveweight, which was significantly lower than the predicted one ($p<0.01$).

C2 A Gompertz analysis of the liveweight gain from 15-30 kg liveweight indicated that the value of the rate parameter B did not differ significantly, the values being 0.0128, 0.0132, 0.0131, 0.0130 (s.e.d. 0.0009) per day, between the feed pairs LB, LH, AB and AH respectively. The average value for these pigs collectively was 0.0130 (s.e. 0.0003) per day, which was not significantly different from the expected value of 0.0135 (s.e. 0.0004) per day for pigs growing at their potential (the value derived from Experiment 3). Pigs given a choice between feeds B and H had an average B value of 0.00129 (s.e. 0.0003) per day, which was also not different from 0.0135 per day, and suggested that these pigs grew also at about their potential.

C3 Pigs given a choice between the two limiting feeds (L and A) had a higher average daily rate of total feed intake than pigs on any other choice (Table 3.6.4). This was in the expected direction (C3) but was not significantly different from the total feed intake of the rest of the pigs, mainly due to the variation in the diets selected by pigs on this feed pair (LA).

TABLE 3.6.4 The average daily rate of total feed intake, daily rate of liveweight gain and FCE of pigs given a choice of two feeds with different CP content, from 15-30 kg liveweight (mean (s.e.))

| Feed pair | Feed Intake (g/d) | Liveweight gain (g/d) | FCE (g of gain/g of feed) |
|---|---|---|---|
| L A | 1106 (19) | 682 (23) | 0.617 (0.021) |
| L B | 1013 (31) | 752 (24) | 0.744 (0.029) |
| L H | 1055 (52) | 768 (33) | 0.730 (0.023) |
| A B | 1028 (63) | 769 (26) | 0.759 (0.058) |
| A H | 1076 (53) | 763 (54) | 0.709 (0.035) |
| B H | 1054 (49) | 764 (13) | 0.730 (0.036) |

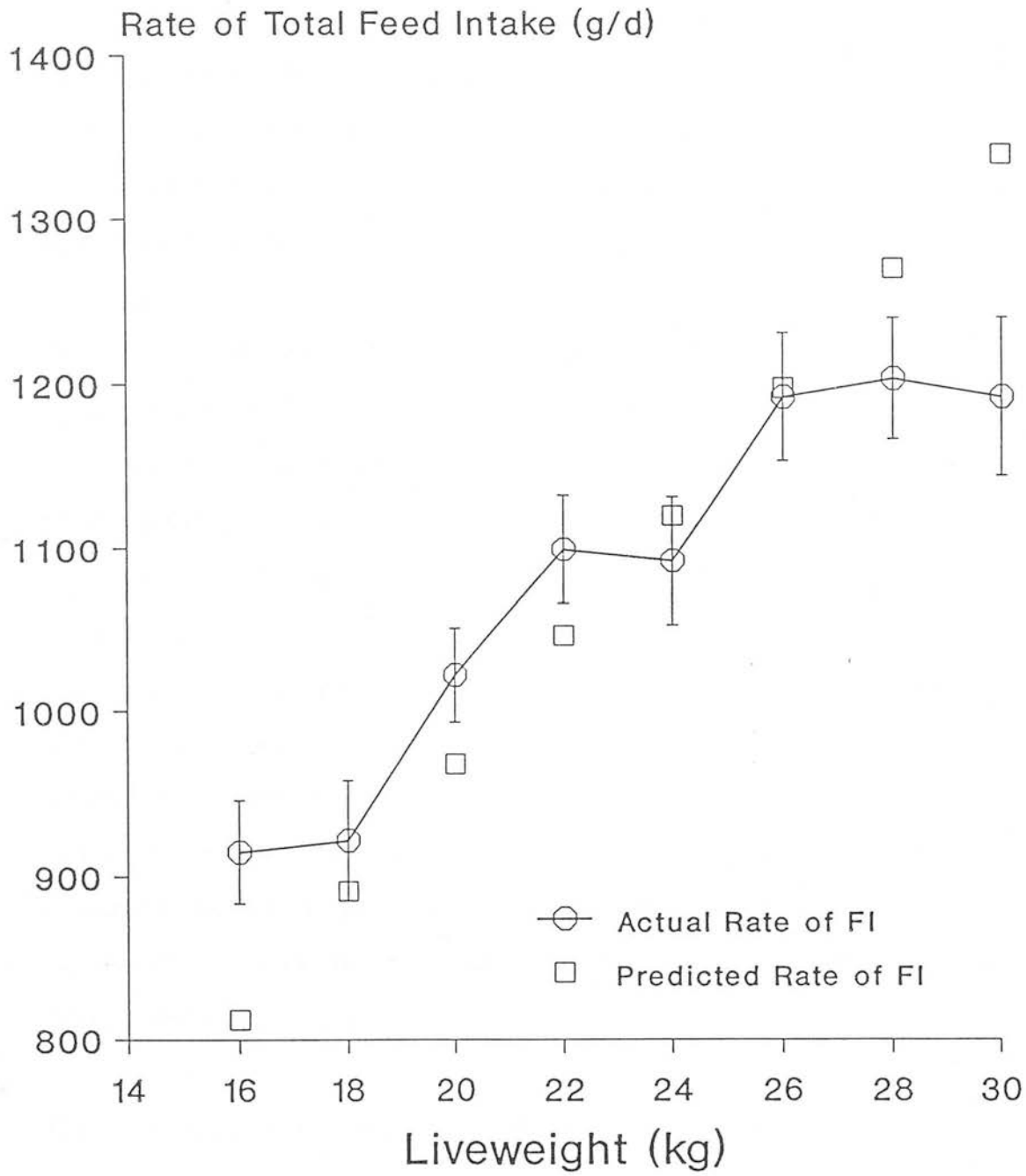


Figure 3.6.6 The actual and predicted rates of total feed intake, at a weight, of the choice-fed pigs.

### 3.7.5 Discussion

The diets selected by the pigs in this experiment were very similar in composition to the ones selected by the pigs in Experiment 3. Pigs given a choice between feeds L and H, from 15 to 24 kg liveweight (the duration of Period I in Experiment 3) selected a diet with 223 (s.e. 7.7) and 221 (s.e. 10.6) g CP per kg fresh feed on average in Experiment 3 (n = 6) and Experiment 4 (n = 4) respectively. As a consequence, they had similar daily rates of liveweight gain (that of their expected potential) and feed intake (that predicted by the Feed Intake Model).

The absence of the expected differences between the diets selected by males and females (Proposition 3: the protein content of the diet selected would be higher in the males than the females) could be attributed to the variation in the diets selected by individual pigs on certain feed pairs. Proposition 3 was based on the suggestion of Chapter I, that male pigs have a higher potential rate of protein gain and a lower desired lipid gain, at a given degree of maturity, than females and consequently, have a higher requirements for protein. There is only one study which compares the effect of sex on the diet selection of pigs, that of Wallace, Palmer, Carpenter and Combs (1973) which concluded that by choice gilts consume a diet with a higher protein content than boars. The value of this study can be questioned since they also measured better FCE and leaner carcasses in gilts, which is in disagreement with the vast majority of the experimental evidence (eg. Batterham, Giles and Dettman, 1985; Giles, Batterham and Dettman, 1986).

The period of six days, in which the animals experienced both feeds that they were then offered as a choice, was used in this experiment in order to ensure that animals would sample considerable amounts of each feed separately. This was based on the method employed successfully in Experiment 3, where pigs were offered a choice between feeds L and H; a choice between two feeds which were clearly distinct from

each other, in terms of the CP they contained. However, it is possible that as the two feeds which are offered as a choice, become closer in nutritional terms, the animals will be less able to discriminate between them (Staddon, 1983). In the limit, the pigs cannot discriminate between two very similar feeds. Therefore, it might be necessary in these cases to extend the duration of the experience period to more than six days, if the pigs are to make 'correct' dietary choices. This suggestion could account for the increased variation in the diets selected by individual pigs in feed pairs where the two feeds were relatively similar (ie. pairs LA and AB).

In an analogous way, the closeness of the two feeds could influence the response to the change in the position of the feeds. In these cases, the animal might take a longer period to discriminate between the two feeds and respond more slowly to the change of the position, by taking a longer period to adjust their diet selection. However, in this experiment there was no relationship between feed-pair and the time course of the response in the change of feed position. The results were similar to those in Experiment 1, in respect to the relatively fast adjustment in the reverse of the feed troughs, and support the idea that animals do not select their diet on the basis of the feed position. They also oppose the argument that: 'it is better to change often the [feed] position around, since animals develop strong positional preferences' (Silverman, 1978; Hughes and Wood-Gush, 1972). In this experiment, pigs used the position of the feed presumably as a cue, but as their apparent positional preferences were easily reversible, it cannot be claimed that they had developed true positional preferences.

It was expected that when animals were offered a choice between two limiting feeds (L and A), they would select only the less limiting one (Proposition 6). This was suggested in accordance with the optimising theory (Krebs and McCleery, 1984), where an animal is expected to choose 'the maximum or minimum subject to specific

constraints'. However, there are two other possible expectations for the diet selection of animals given a choice between two limiting feeds:

(i) animals will not be able to discriminate between the two feeds, since they will be both classified as failing to meet their requirements, or

(ii) animals will prefer the less limiting feed, but they will also sample substantial amounts from the other feed.

The first expectation implies that animals will either select 50-50 per cent from the two troughs, or that some animals will eat only feed L and others only feed A; the variation between individuals will depend on simple preferences (eg. positional preferences). Such an outcome was observed by Holcomb *et al* (1976) when they offered laying hens a choice between two feeds with 8 and 11 per cent crude protein, both of which feeds were below the hen's crude protein requirements. Their diet selection was indistinguishable from random selection, although it appeared to show systematic variation. However, a significant part of their results could be simply attributed to the frequent change in the position of the feeds.

The second expectation is a logical extension of the optimising theory (Krebs and McCleery, 1984). Animals prefer the less limiting feed, but continue to explore the trough with the other feed. Such behaviour, which might seem unnecessary for domesticated species, is of major importance for foraging animals. Foraging animals need continuously to be informed about the quality of their foraging patches, since the quality of a patch could decline as a result of their foraging activity (Charnov, Orians and Hyatt, 1976). Some have argued that this monitoring behaviour, which is of obvious advantage, must be maintained at all cost - even if it is consistently punished (Shettleworth, 1978; Lea, 1979). The results of this experiment tend to agree with the second suggestion. Three out of four animals on the LA treatment preferred feed A, but continued to consume some L; the amount of L consumed

varied somewhat among individuals (prop. L 97 (s.e. 71) g/kg TFI). The fourth animal preferred feed L, but its preference changed with time (Figure 3.6.5). During the last seven days of the experiment, this animal consumed more of the feed A and its reversed preference continued even after the change in the position of the feeds. One could, therefore, argue that if the experiment had been continued, the fourth animal would have exhibited a similar choice to the other three.

The principal of optimising theory could also apply when animals are offered a choice between two feeds which are above their requirements. Models which have dealt with such situations suggest that once the animal has met its requirement for a nutrient, further intake has no advantage (eg. a model for the sodium requirement of the moose; Belovsky, 1978). Strong support for this was given by the experiments of Musten *et al* (1974) on rats, and Cropper (1987) on sheep. In both cases animals avoided the feed overabundant in CP and consumed the less abundant one. This suggested that the animal has no obvious advantage in overloading its deaminating system (Harper, 1974).

The proposition that pigs will avoid excess protein intake (Proposition 5) has also survived the test of this experiment. Pigs preferred feed B and avoided almost completely feed H (an excess of protein intake). The fact that feed H was not generally avoided was shown by the LH and AH data, where pigs consumed considerable amounts of feed H. Pigs on pair BH were offered the choice between the two feeds at a heavier weight than pigs on any other feed pair (this was the result of the experience period) and therefore feed B was close to their requirement, or even abundant, at that stage. The small amounts of feed consumed from the trough containing H may represent the attempt of the animal to remain informed about any changes in the quality of the feeds on offer. The variation in the diets selected by individual pigs on this feed pair (BH) was very small, although the two feeds appeared to be as relatively close as feeds L and A, or A and B in the

appropriate pairs. However, since the error is often proportional to the absolute value of the coded quantity (the Weber-Fechner relation[5]), then feeds B and H were quite distinct in terms of their nutritional properties for the pigs.

The experiment described here, comprises a comprehensive investigation into the rules of one aspect of diet selection. The fact that pigs grew at a rate which was presumed to be their potential, suggests that choice feeding can be used as a means of determining the animal's requirements for a given resource.

### 3.7.6 CONCLUSIONS

The results from this experiment supported the theory that pigs, given a choice between a suitable pair of feeds, will choose a balanced diet and will attain their potential growth. In less favourable conditions (ie. a choice between two limiting feeds) they will select the best possible diet - subject to specific constraints. It is therefore concluded that pigs selected a diet:

(a) in a directed manner

(b) which changed as they grew

(c) which was not first limiting in a nutrient and hence, in quantity reflected their requirements for maintenance, growth and fattening

(d) independently of feed position

(e) which minimised excess of protein intake.

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5 *The Weber-Fechner relation implies that the effect of the same difference is substantial at the low end of the scale, but less impressive at the high end. This dependence of differential sensitivity on base values is characteristic of many physical dimensions, notably sound and light intensity, and time: for example, a second is a lot when one is judging intervals ont he order of 3 or 4 seconds; it is not so much when judging intervals in the order of minutes.*

## 4.1 INTRODUCTION

Previous chapters have dealt with the ability of pigs to select a diet which supported their potential growth. The diet selected by each pig met its apparent requirements to the time and state, and was a reflection of the pig's degree of maturity, genotype and sex. The experiments described so far have stressed the difference in the diet selection between the sexes and the ages. It was shown, for example, that older pigs selected a diet with a lower protein content than younger pigs, a fact which reflected the increased proportion of lipid in the gain of the empty body as pigs matured and the increased energy costs of maintenance as the pigs increased in size.

Here, it is also suggested that animals of similar degrees of maturity, but of different genotypes, will select diets of different compositions, according to their inherited growth plan. Such a comparative study has not yet been performed on domestic animals, with the exception of experiments on poultry (Emmans, 1977). However, these experiments did not show substantial differences in the diets selected, mainly due to the genotypic similarity of the lines of hens used.

An alternative and more severe test of the theory of diet selection would be to use animals that are given the opportunity to recover on a set of feeds, after a period of feeding either on an imbalanced feed or on a constrained feeding regime. In these cases, the animal has been diverted from its inherited path of growth, and it is possible that its diet selection will differ from that of a continuously grown animal. If the diets selected by realimented[6] animals are to be predicted, it first needs to be known what the effects of the initial limitation on the body composition and the development of the animal were, and second what the response of animals to the restoration of non-limiting conditions will be. For example, the question as to

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6 *In this chapter, realimentation will always be taken as the restoration of non-limiting conditions (Chapter II).*

whether the effects of limitation are permanent or recoupable has evoked a considerable amount of research into the growth recovery of farm animals; it has often been suggested that animals are able to compensate for the time lost during a phase of restricted growth, when realimented (Wilson and Osbourn, 1960; Allden, 1968).

This chapter deals with the diets selected by pigs prevented from growing on their inherited path and examines the effects of body composition on diet selection. In doing so, the effects of limiting conditions on body composition are considered and a theory of growth after the restoration of non-limiting is proposed.

## 4.2 THE EFFECT OF LIMITING FEEDING ON BODY COMPOSITION AND DEVELOPMENT

The possible effects on protein and lipid gain (or more helpfully the lipid:protein ratio of the empty body) when an animal is fed on an imbalanced feed or is controlled or constrained in its feeding, are illustrated in Figure 4.1. The solid lines on the figure represent the path of the potential protein growth (4.1.i) and the lipid:protein ratio (4.1.ii) of pigs grown under non-limiting conditions. A limited animal (dotted lines) may grow protein at a slower rate and therefore take a longer time ($\Delta t$) to achieve a similar protein weight (4.1.i), and its lipid weight may be lower ($-\Delta l$) or higher ($+\Delta l$) at a given protein weight (4.1.ii), compared with a similar animal treated in a non-limiting way. The combination of $\Delta t$ and $\Delta l$ can be seen forming the following five classes:

(a) Protein growth rate is limited and the lipid:protein ratio of the empty body is more than desired ($\Delta t>0$ and $\Delta l>0$). This is usually the outcome of *ad libitum* feeding on a low protein feed (Chapters II, III).

(b) Protein growth rate is limited and the lipid:protein ratio of the empty body is equal to that desired ($\Delta t>0$ and $\Delta l=0$). Not a very common observation in

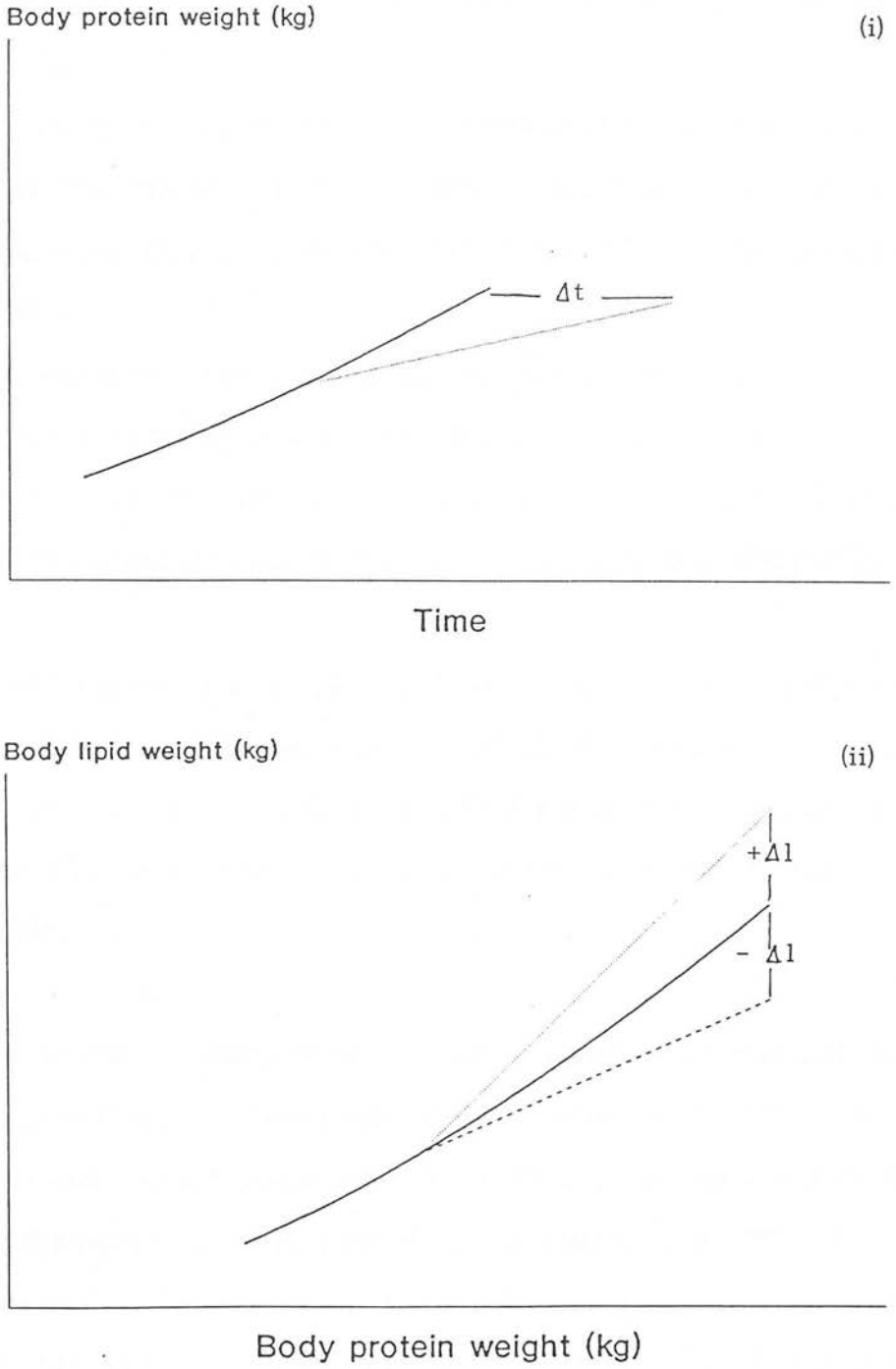



Figure 4.1 Possible effects of limiting feeding conditions on protein growth (i) and lipid gain (ii). (————) Unlimited and (.....) limited animals.

restricted feeding experiments with pigs, but often the outcome of similar experiments on other species (ie. sheep) (Burton and Reid, 1969; Searle and Graham, 1975).

(c) Protein growth rate is limited and the lipid:protein ratio of the empty body is less than desired ( $\Delta t>0$ and $\Delta l<0$). The usual outcome of restricted experiment on pigs (McMeekan, 1940, a, b, c; Campell, Taverner and Curic, 1983).

(d) Protein growth rate is non-limited and the lipid:protein ratio of the empty body is more than desired ( $\Delta t = 0$ and $\Delta l > 0$). This could be observed when an animal is given *ad libit*um access to an imbalanced feed (in relation to its nutrient:energy ratio) in a non-limiting environment (Chapter II).

(e) Protein growth rate is non-limited and the lipid:protein ratio of the empty body is less than desired ( $\Delta t = 0$ and $\Delta l <0$). An attractive combination, since it offers the possibility of achieving maximum protein growth whilst avoiding the deposition of excess fat, under certain feeding regimes (Hodge, 1974).

The effect of limiting feeding on the development of the body is restricted mainly to body fat since it has been clearly demonstrated that the growth of the other tissues, relative to each other, is remarkably homeostatic after allowance is made for the stage of development at which comparisons are made (Wilson, 1952, 1954; Elsley, McDonald and Fowler, 1964). The animal inherits a growth plan that leads to a strongly fixed form for the lipid-free empty body at maturity. At any degree of maturity the animal has a certain form to the lipid-free empty body, which is independent of the pathway to maturity.

There are only minor exceptions that deviate from this fixity of form (eg. head; Elsley *et al*, 1964; stomach and liver; Palsson and Verges, 1952a, b). Restricted pigs

had relatively less weight of the feed processing organs (ie. gastrointestinal tract, liver and pancreas) than the *ad libitum* fed controls (Stamataris *et al*, 1985), as did sheep on a low plane of nutrition (Palsson and Verges, 1952a, b). These departures may indicate the adaptive ability of animals to grow their feed processing organs at a slower rate when feed is scarce. However, they represent only small deviations when compared with the plasticity of the fatty tissue and its ability to be grossly manipulated by the plane of nutrition.

## 4.3 A THEORY OF GROWTH RECOVERY

Following a period of feeding under limiting conditions the growing animal may have less protein, or lipid or both, at some point when that limitation ends, than it would have had on non-limiting feeding conditions. Then the questions to ask are:

1. can the animal, following a period of under-feeding, grow protein faster at a given protein weight and thus reduce its time loss?,
2. can lipid be recovered and the animal return to its normal fatness at a given protein weight?

To predict growth recovery it can be hypothesised that:

(a) A realimented animal will seek to resume the rate of growth known to be its potential and therefore time lost during limitation will not be regained.

(b) A realimented animal will seek to replenish, if necessary, its fat stores to the level set by its inheritance.

(c) A realimented animal will seek to increase its feed intake to satisfy the released impulse to grow. The concomitant effects of the increase in feed intake are that the realimented animal will:

(i) restore (increase) its gut contents, and

(ii) restitute the capacity and weight of its feed processing organs to the size set by its growth plan.

### 4.3.1 The Retention of the Potential for Growth

The assumption that a realimented animal will seek to resume the rate of growth known to be its potential, rests on the idea that an animal will retain throughout its life the ability to grow protein at a maximum rate set by its inheritance and that potential protein growth becomes actual under non-limiting conditions (Chapter II).

The idea that animals maintain the impulse and the ability to grow, even beyond the age where normally growth has ceased to be observed, is supported by the findings of several experiments (Moulton, Trowbridge and Haigh, 1921; McCance and Widdowson, 1962). Morse and Vohra (1971) observed an analogy of growth curves between restricted and re-fed Japanese quail and their continuously-fed contemporaries, regardless of the duration of the intake restraint (Figure 4.2) The growth of animals, after realimentation, remained dependent on their mature size, their current size, and the direction of their impulse to grow.

Moulton *et al* (1921), Elsley (1963) and Morse and Vohra (1971) did not observe any difference in the growth rates between the realimented animals and their non-limited counterparts at the same degree of maturity. However, the majority of the trials studying the growth performance of previously restricted animals have commented on a marked increase in growth rate (or an accelerated rate of protein gain) and feed conversion efficiency, immediately following restoration of non-limiting conditions (Lucas, Livingstone and McDonald, 1962; Robinson, 1964; Cole, Duckworth, Holmes and Cuthbertson, 1968; Tullis, 1981; Stamataris *et al*, 1985) with the severest limitation producing the greatest boost to growth rate (Wilson and Osbourn, 1960).

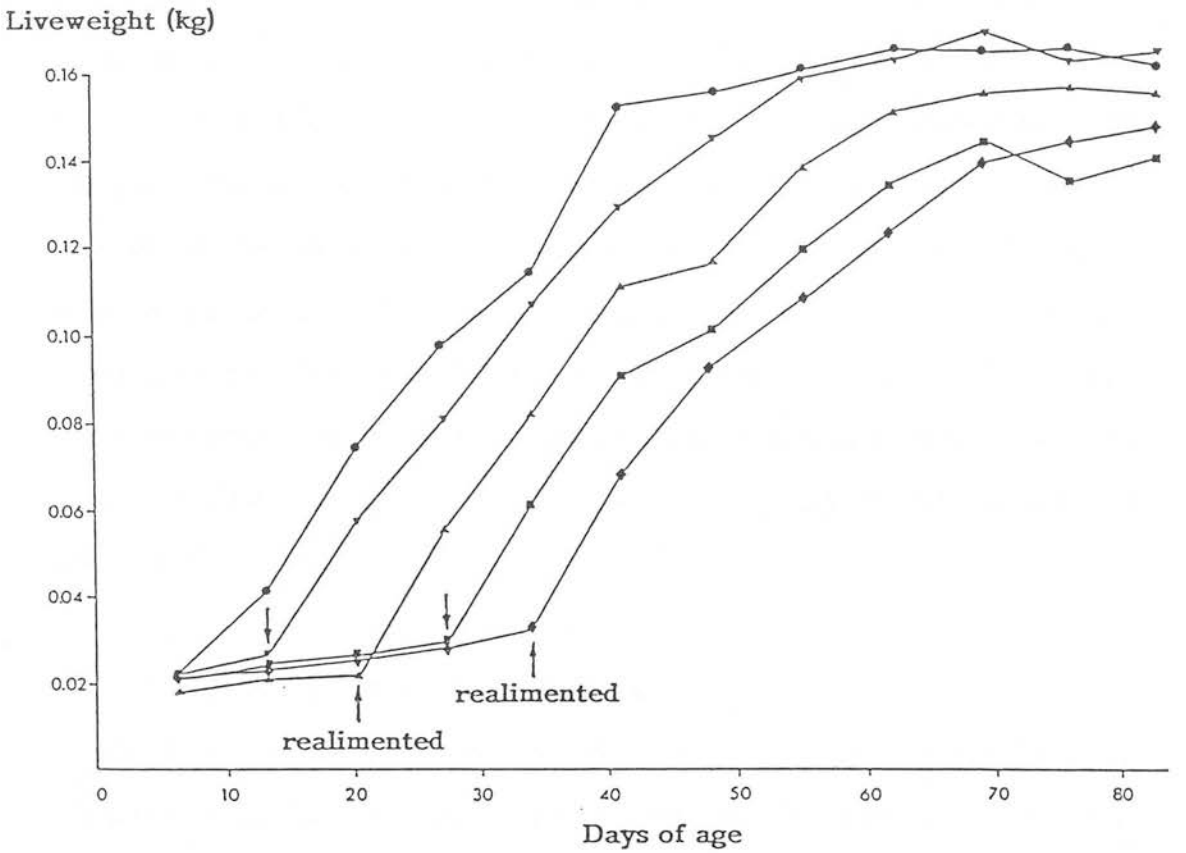


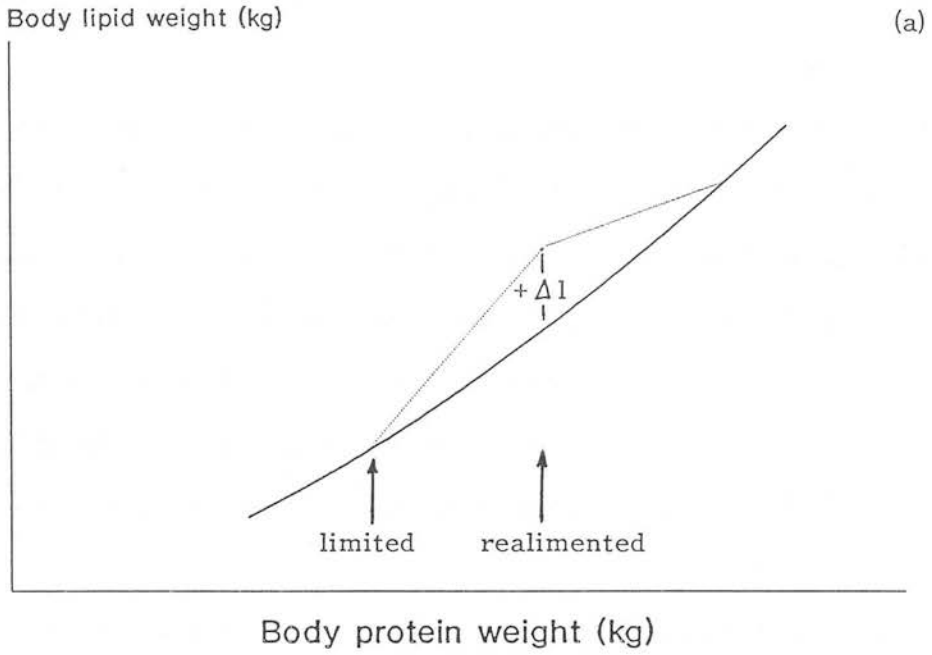

Figure 4.2 Changes in live weight (kg) between 6 and 83 days of age of Japanese quail (*Coturnix*) fed to appetite (●) or restricted for 7 (▼), 20 (▲), 27 (■) or 34 (◆) days and realimented (Morse and Vohra, 1971).

However, realimented animals are expected to restitute their feed processing organs in response to the increased load of feed, when necessary (Thornton, Hood, Jones and Re, 1979; Tullis, 1981), and this restitution of the organs has probably led to the faster protein gains observed by these animals. There are adequate reasons for suggesting this. Thornton *et al* (1979) and Tullis (1981) openly suggested that the extra gain in protein was all gain in organ protein. Burton, Anderson and Reid (1974) reported that the increase in protein gain was accompanied by an increase in water gain in their experiment, which was probably the effect of rehydration of gut tissue. Stamataris *et al* (1985) have clearly shown that the realimented animals were able to grow their feed processing organs twice as fast as continuously fed animals. Therefore, authors who have often reported faster protein gains may in fact have recorded a similar restitution of the feed processing organs and not any true compensatory growth.

### 4.3.2 The Restoration of the Desired Fatness

The idea that an animal inherits not only its potential rate of protein growth but also a desired level of fatness was introduced in Chapter I. The theory stated that, under non-limiting conditions, the lipid gain of the animal is related in a definitive way to the growth of protein.

The theory of growth recovery suggests that the subsequent rate of lipid gain will be dependent on the fatness of the animal after feed restriction has ended. Since the usual outcome of restricted feeding experiments on pigs is a reduced lipid:protein ratio at a protein weight (McMeekan, 1940a; Lucas *et al*, 1962; Ratcliffe and Fowler, 1980) (Figure 4.3 (b)), the theory of recovery growth predicts that the animal will retain the desire to restore its depleted fat stores. In an analogous way to the retention of the potential for growth, the rate of fattening will be dependent on the state of the animal (degree of maturity and degree of fatness). Experimental evidence from pigs and other species provide ample support for faster lipid gain in



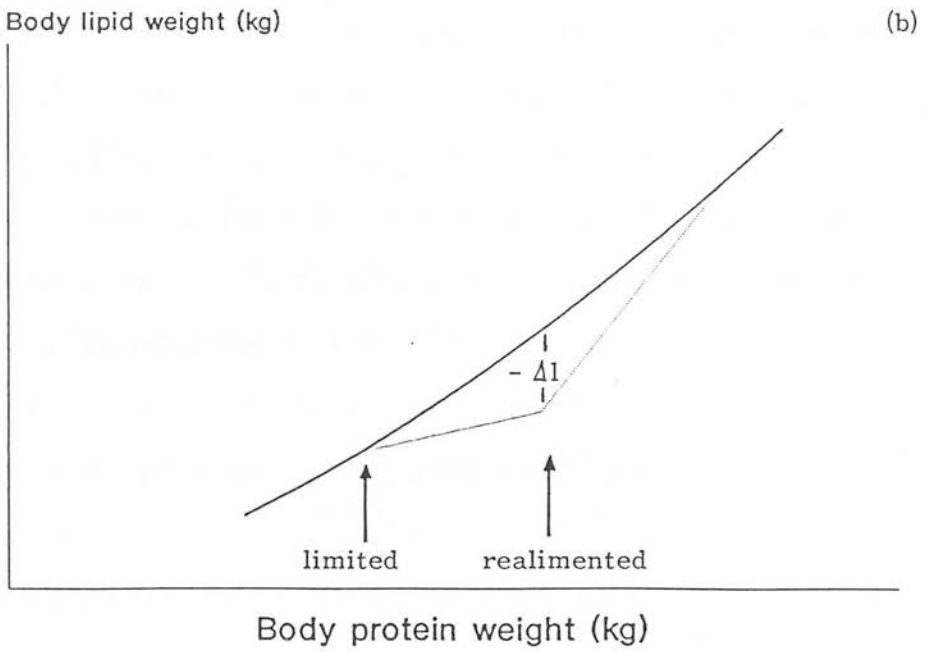




Figure 4.3 Restoration of the lipid:protein ratio in the empty body. (a) Lipid:protein ratio greater than desired. (b) Lipid:protein ratio less than desired.

realimented animals than their non-limiting fed counterparts (Wilson and Osbourn, 1960; Cole *et al*, 1968; Tullis, 1981).

Recovery experiments, which deal with animals that had a lipid:protein ratio greater than desired at the end of limitation (Figure 4.3 (a)), can also be seen in relation to the theory that animals attempt to restore (correct) their desired level of fatness. A 'compensatory thinning' or a very slow lipid gain was observed in such an experiment by Stamataris *et al* (1985). The rate of lipid gain of pigs with an excessively high lipid:protein ratio was significantly smaller than that of 'normal' pigs, when they were offered *ad libitum* access to the same high protein:energy ratio feed.

Feed intake after realimentation can then be viewed in respect of the state of the animal and the direction of its impulse for growth of protein and fat after restriction. The common observation that realimented pigs eat at a higher rate than continuously grown animals (Cole *et al*, 1968; Owen, Ridgman and Wyllie, 1971; Stamataris *et al*, 1985; Donken, Den, Hartog, Brascamp, Merks, Noordewier and Buting, 1986) can be explained as being the attempt by the animal to replenish fat stores and restore its desired level of fatness. On the other hand, the theory of recovery predicts that there will be occasions where the feed intake will be less for realimented animals than that of continuously grown controls, at the same degree of maturity, when the outcome of restriction is a lipid:protein ratio greater than that desired.

## 4.4 DIET SELECTION IN REALIMENTED ANIMALS

The theory of recovery growth predicts that realimentation is mainly characterised by the animal's attempt to restore its body fatness to the level set by its inheritance. Therefore, when a previously limited animal is given the opportunity to recover on a set of feeds , it is expected to select a diet that reflects the impulse to restore its desired level of fatness. Pigs with a higher lipid:protein ratio than the desired

( $\Delta I>0$) are expected to select a diet of a higher protein:energy ratio than pigs with a desired level of fatness. Similarly, pigs with a lipid:protein ratio less than desired ($\Delta I<0$) are expected to select a diet with a lower protein:energy ratio than pigs grown on their inherited path of growth. These differences in diet selection are expected to cease once the lipid:protein ratio is restored to that of the desired.

Unfortunately, the existing literature on the effects of body composition on the diets selected by realimented animals is limited (Table 4.1). The small number of studies on the subject belongs either to the class of experiments where animals were fasted, or where they were restricted (or deprived) of protein, before they were offered a choice of feeds. The methodology of these experiments does not always permit sensible conclusions. The animals used were mainly adult rats or hamsters, and there was not always sufficient information about their body state at the end of restriction, such that recovery growth can be sufficiently explained and the diet selection could be compared with the expectations.

However, where the data are presented in a way that permits comparisons to be carried out, there is a clear indication that realimented animals selected a diet that allowed them to resume their desired body state. Fasted animals (Andik *et al*, 1951; Schutz and Pilgrim, 1954; Piquard *et al*, 1978) increased their rate of feed intake when choice fed and the main energy source preferred was fat. This expected increase in feed intake appears to represent the desire of the animal to replenish its body fatness, and the increased preference was for fat which is converted efficiently into body fat (ARC, 1981). Similarly, protein deprived animals (Di Battista, 1987) increased their protein intake when fed on a set of feeds and the increase was influenced by the nature of the protein restriction schedule. Piquard *et al* (1978) reported that '... protein intake (in realimented rats) was increased twofold and compensated exactly for the protein lack. The carbohydrate intake, during this period was decreased so that total energy intake was unchanged'.

TABLE 4.1 A summary of experiments on growth recovery on a set of feeds

| | Fasting | Protein deprivation/ restriction | Kind of animal |
|---|---|---|---|
| Andik, Donhoffer, Moring and Szentes (1951) | + | | male rats |
| Schutz and Pilgrim (1954) | + | | male rats |
| Hilman and Riopelle (1971) | | + | female Rhesus monkeys |
| Szepesi and Oney (1977) | | + | male rats |
| Piquard, Schaefer and Habery (1978) | + | + | male rats |
| Kratz and Levitsky(1979) | | + | female rats |
| Di Battista (1986) | + | | male hamsters |
| Di Battista (1987) | | + | male adult hamsters |

Therefore, the experimental evidence quoted lies in favour of the idea that a realimented animal will select a diet that allows it to resume its growth plan. Consequently, the experimental part of this chapter reports the findings of an experiment designed to test the above idea. Previously limited pigs were given a choice between two feeds which varied in their protein:energy ratio, and their diet selected was to be compared with that of animals of a similar degree of maturity, but grown on their inherited path.

## 4.5 EXPERIMENT 5. THE EFFECT OF BODY COMPOSITION ON DIET SELECTION

### 4.5.1 Objectives

The experiment tested the idea that realimented animals select their diets in order to restore their desired level of fatness. The realimented pigs were given access to a low protein feed, so that their growth rate was slow and their body fatness was diverted from their desired lipid:protein ratio. To exaggerate the effects of such limitation, the experiment was conducted in lower ambient temperatures than the previous ones. Such a treatment has the advantages that the effects on body composition could be seen within a short period of time and the comparison between the diets selected be made more clearly. The body composition of the realimented animals and the ones grown under non-limiting conditions was estimated by serial slaughtering.

### 4.5.2 Materials and Methods

The housing and management procedures were identical to those described in the previous chapters.

*Animals*. Forty Cotswold Large White x Landrace pigs (20 entire males and 20 females) from 7 litters, were individually caged in the controlled environment portacabin used for the previous experiments. The animals were moved immediately after weaning at 4 weeks of age and had a mean liveweight of 6.82 (s.d. 1.01) kg, having been offered no supplementary feed prior to weaning.

*Feed*. Two feeds (L and H) with identical formulations as feeds L and H in Experiments 3 and 4, were made into pellets (Table 4.2). The size of the pellets (3 mm diameter) was smaller than that previously used since the feeds were offered to younger pigs. The estimated analysis of the feeds is given in Table 4.3. The two feeds had a slightly higher protein content than the feeds in the previous two experiments; this was attributed to the variation in the raw materials used.

**Methods**

*Experimental Design*. The experiment consisted of two periods (Table 4.4).

*Period A*. During this period half of the animals were offered free and continuous access to feed L and half to feed H. The objective was to create two groups of pigs with different body compositions: pigs on L (limiting in CP) were expected to have an increased fatness (fat pigs - F) and pigs on H to have their desired or a slightly reduced fatness (thin pigs - T). Since the difference between the two groups was intended to be as great as possible, the two feeds were offered as soon as the animals were moved into the individual cages. This part of the experiment ended when each animal reached 16 kg liveweight. During Period A five animals (two on L and three on H) died or became very ill from scouring due to colibacillosis, and had to be replaced with animals from another litter.

*Period B*. At 16 kg liveweight the fat pigs (F) were allocated to one of the three treatments: *ad libitum* access to feed L (treatment FL- four pigs), *ad libitum* access to

TABLE 4.2 The composition of the two feeds (kg/tn fresh weight) used in Experiment 5.

| Ingredients (kg/tn) | FEED L | FEED H |
|---|---|---|
| Herring meal | - | 225 |
| Oatflakes | 727 | 347 |
| Milk replacer | 185 | 350 |
| Molasses | 50 | 50 |
| PT10C Vitamin and Mineral supplement[a] | 5 | 5 |
| Vitamin E supplement | 7.5 | 10.5 |
| Salt | 2.5 | 2.5 |
| Dicalcium Phosphate | 23 | 10 |
| | 1000 | 1000 |

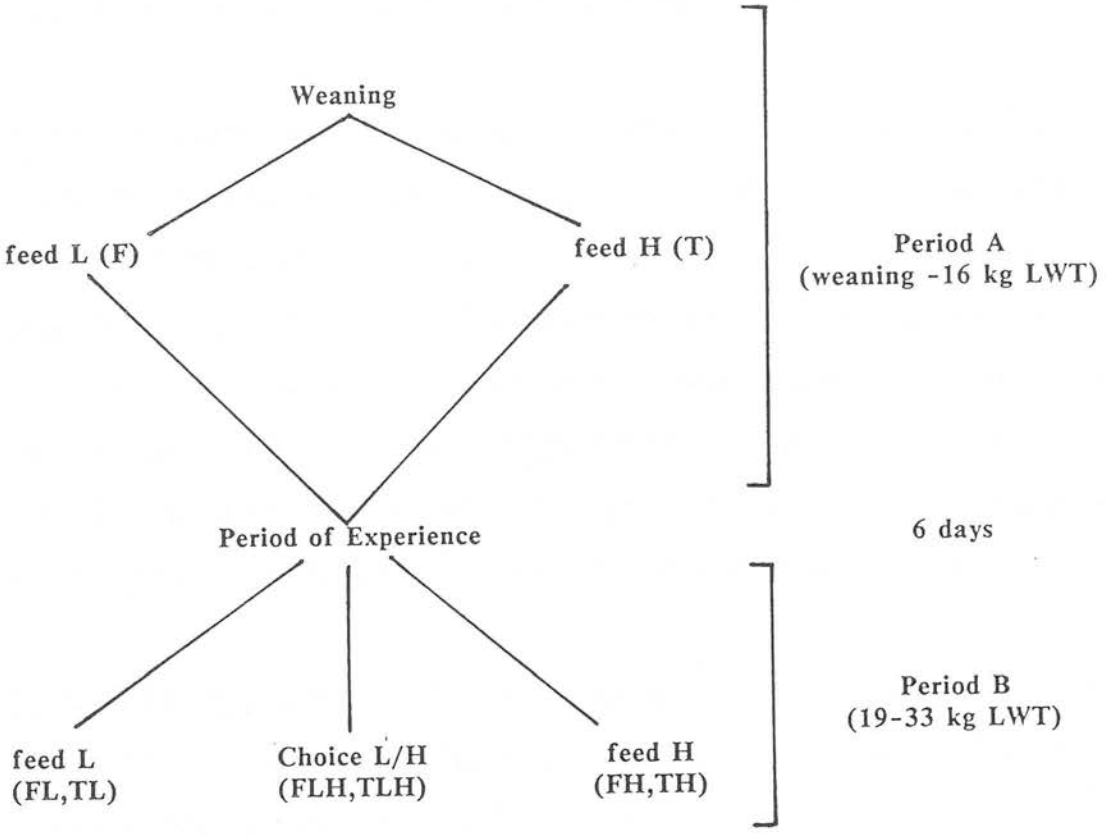
a See Table 2.3

**TABLE 4.3** The chemical analysis of the two feeds (g/kg fresh weight) used in Experiment 5.

| Component (g/kg) | FEED L | FEED H |
|---|---|---|
| Digestible energy[a] (MJ/kg) | 15.8 | 17.1 |
| Dry Matter | 921 | 920 |
| Crude Protein (CP) | 134 | 278 |
| Ether extract | 79 | 80 |
| Ash | 58 | 87 |
| Crude fibre | 15 | 13 |
| Gross energy (MJ/kg) | 17.0 | 17.4 |

a values calculated from feed tables

TABLE 4.4 The design of Experiment 6



H (treatment FH - four pigs), and a choice between feeds L and H (treatment FLH - eight pigs). The same numbers of thin pigs (T) were allocated to identical treatments (treatments TL, TH and TLH). The animals were randomly allocated to the treatments, taking account of age at 16 kg and with a restriction for litter origin. Each treatment had an equal number of animals from each sex.

It was felt necessary, according to the findings of Experiment 3, that the choice fed animals had to experience separately the two feeds, which were given as a choice. Therefore, feeds L and H were offered singly on alternate days, for a period of 6 days (the last day of Period A, on feed L or H, was considered to be the first day of this period). The position of the feeds did not change throughout the experiment (the experience period included) but the position of the feeds was randomised across pigs. During the experience period both troughs were present in the cage, but only one was filled. Period B ended when each animal reached 33 kg liveweight.

*Slaughter Schedule*. Since one of the experimental objectives was to investigate the effects of body fatness on diet selection, an estimation of the effects of the two feeds on body composition and hence the lipid content of the animal at 16 kg was needed. However, the introduction of the experience period, although necessary (Chapter III), imposed a complicating factor on the experimental design. It was then decided that the estimation of the body composition should follow the experience period. To achieve sensible comparisons between choice and single fed pigs, single fed animals (treatments FL, FH, TL and TH) were also given the experience schedule (feeds L and H were offered single on alternate days, for a period of 6 days).

At the end of the experience period four fat (F) and four thin (T) pigs (two from each sex) were sacrificed. The initial liveweight at the beginning of Period A was taken into account: the animals were divided into two equal groups of heavy and

light piglets; equal numbers (selected at random) from each group were then slaughtered.

At the end of the experiment (at 33 kg liveweight) all the choice-fed animals were slaughtered.

*Slaughter procedure and chemical analysis*. These procedures were similar to those described in Chapter II. On the day of slaughter the pig was weighed and its weight was recorded. The feeding trough was also removed and the feed intake was recorded. At 1400 hours the animal was killed and it was transported immediately to the slaughter facilities.

*Management*. The animals were weighed daily and fed twice a day (morning and afternoon). The weighing procedure started at 0900 hours and followed the same animal sequence every day. The feeding routine began immediately after weighing and also followed the same animal sequence.

The temperature was set at 28$^{o}$C initially, in an attempt to overcome the post-weaning stress. When all animals began to consume appreciable amounts of feed, it was very rapidly lowered by 1-1.5$^{o}$C per day. The house temperature aimed for was 16$^{o}$C at 16 kg liveweight.

### 4.5.3 Propositions

The experimental propositions fell into three categories according to whether F or T pigs were given:

(a) a choice between feeds L and H

(b) free and continuous access to feed H, or

(c) free and continuous access to feed L.

**Propositions (1A-5A). Pigs given a choice between L and H**

P1 The F pigs will resume protein growth at the same rate as T pigs at comparable degrees of maturity. This rate of growth will be demonstrably that of their potential.

P2 The F pigs will reduce the lipid:protein ratio in their empty bodies to the same lipid:protein ratio of the T pigs. This lipid:protein ratio will be set by their inheritance.

P3 The F pigs will select a diet of a higher protein content than T pigs in order to:

(a) satisfy the residing and now released impulse to grow and

(b) restore the desired lipid:protein ratio

P4 Male (F or T pigs) will select a diet of a higher protein content than female pigs, to meet their different requirements for growth.

P5 The F pigs will have a slower liveweight gain than T pigs, as a consequence of their reduced gain in fat. Differences in feed conversion efficiencies will result from differences in the rate and composition of the liveweight gain..

**Propositions (1B-2B). Pigs given access to H only**

P1 The F pigs will have a reduced rate of feed intake, when compared with T pigs, in order to restore their lipid:protein ratio in their empty bodies.

P2 The F pigs will have a slower liveweight gain than T pigs, as a consequence of their reduced gain in fat and their protein gain at a rate set by their potential. Differences in feed conversion efficiencies will result from differences in the rate and composition of the liveweight gain.

**Propositions (1C-2C). Pigs given access to L only.**

P1 The rate of feed intake will be similar between F and T pigs. This rate of feed intake will be predicted by the Feed Intake Model.

P2 Both F and T pigs will have similar slow liveweight gains and poor feed conversion efficiencies (when compared with pigs of all the other treatments) since they will be limited by their protein intake.

### 4.5.4 Results

#### (i) Period A : Weaning - 16 kg

*(a) Liveweight Gain (LWG)*

To exclude the effects of the post weaning stress (which were variable between pigs), the analysis considered the liveweight gains and feed intakes from 9 kg liveweight. Figure 4.4 shows that F pigs took significantly more time ($p<0.001$) to reach 16 kg liveweight than T pigs. The rates of liveweight gain of the two groups from 9-16 kg liveweight were 386 (s.e. 10) g/day and 591 (s.e. 14) g/day respectively (Table 4.5). There were no significant differences in the rates of liveweight gain between the sexes, but the interaction between treatment x sex just failed to meet significance ($0.1< p<0.05$). This was attributed to the faster rates of liveweight gain which were achieved by the female over the male F pigs (408 (s.e. 13) g/day and 364 (s.e. 12) g/day respectively). A comparison with the Gompertz description of liveweight gain taken from Chapter I suggested that T pigs had received non-limiting conditions up to 16 kg liveweight. The B value was calculated to be 0.0150 (s.e. 0.0018) and 0.0152 (s.e. 0.00138) per day for the males and females respectively.

*(b) Feed Intake and Feed Conversion Efficiency (FCE)*

The effects of treatment (level of crude protein in the feed) on feed intake and FCE are described in Table 4.5. The table shows that F animals had a higher rate of feed intake and converted feed less efficiently than T pigs, during the 9-16 kg liveweight interval. Both these differences were highly significant ($p<0.001$). Female pigs (in both treatments) appeared to have a higher rate of feed intake, but the difference was not significant.

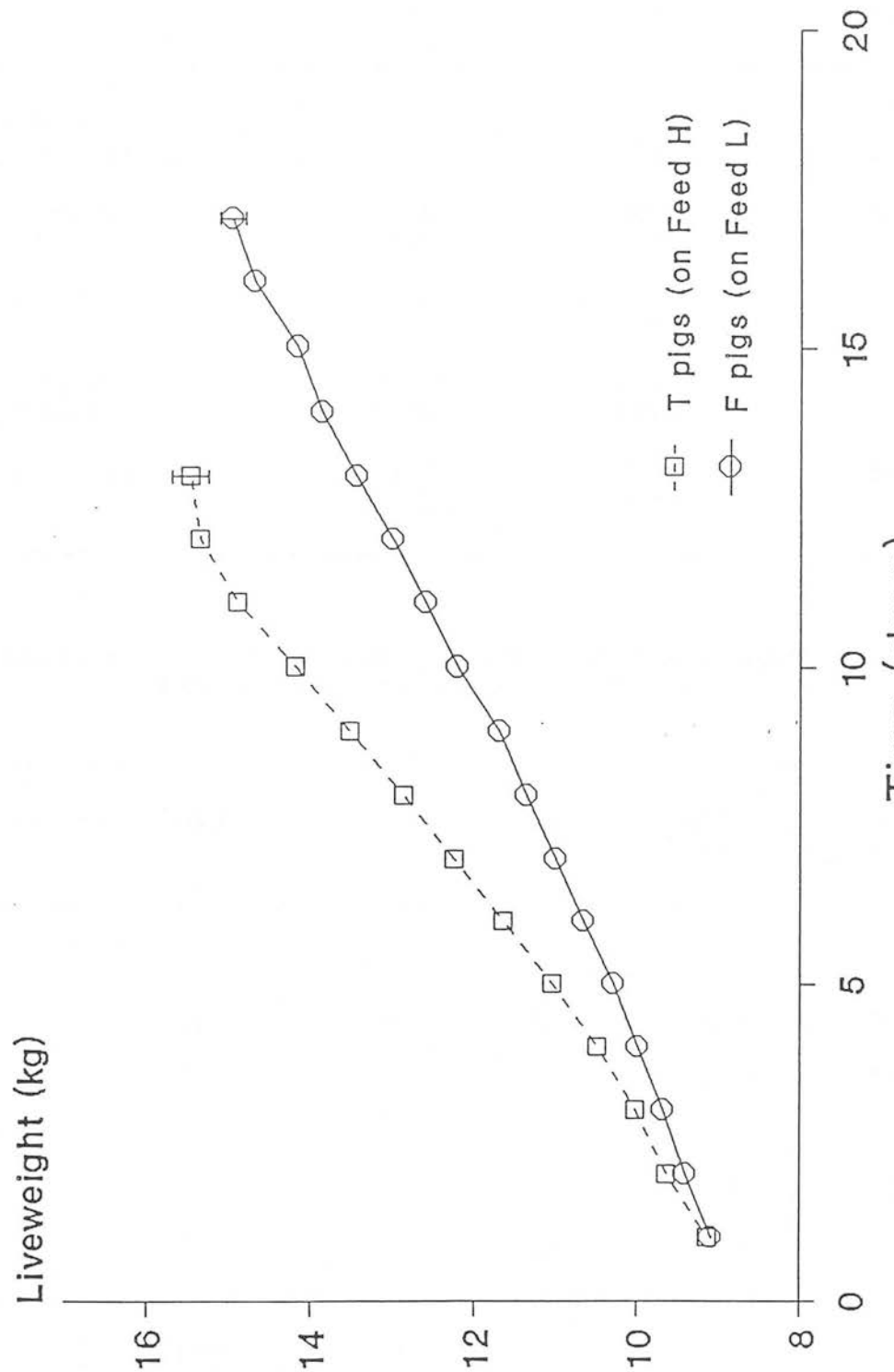



Figure 4.4 The effect of treatment (level of crude protein) on the liveweight gain of F and T pigs.

**TABLE 4.5** **Effects of treatment (level of crude protein in the feed) on rate of feed intake, daily rate of liveweight gain and FCE of F and T pigs, from 9-16 kg liveweight (mean (s.e.)).**

| | Treatment F | T | s.e.d. |
|---|---|---|---|
| CP content (g/kg fresh feed) | 134 | 278 | - |
| Feed Intake (g/d) | 749 (14) | 666 (17) | 21 |
| Gain (g/d) | 386 (10) | 591 (14) | 17 |
| FCE (g of gain/ g of feed) | 0.517 (0.007) | 0.891 (0.018) | 0.019 |
| Time in days | 11.5 (0.29) | 17.5 (0.44) | 0.46 |

**TABLE 4.6** **The daily liveweight gain and feed intakes, averaged over three days for F or T pigs eating a high (H) or low (L) protein feed.**

| Treatment | Feed | n | Gain g | Feed Intake g | FCE (g gain/g feed) |
|---|---|---|---|---|---|
| T | | 20[a] | | | |
| | H | | 655 | 844[d] | 0.775 |
| | L | | 610 | 1071 | 0.580 |
| F | | 20[b] | | | |
| | H | | 1061[c] | 1078 | 0.983 |
| | L | | 575 | 1027 | 0.560 |

a One day missing for 2 animals
b One day missing for 1 animal
c Significantly greater ($P<0.001$) than the other three values
d Significantly less ($P>0.001$) than the other three values

Since the ambient temperature rapidly declined from 28 to 16$^{o}$C in Period A, pigs were at different stages of their growing when these changes in temperature occurred. Therefore, it was decided not to present the individual graphs of the daily feed intake for each pig (from 9-16 kg liveweight) and not to test each point against the predictions of the Feed Intake Model.

**(ii) Period of Experience : 5 days from 16 kg LWT**

For the purposes of the statistical analysis, the liveweight gain and feed intake of the last day of Period A were considered together with the 5 days of the period of experience. The results were then analysed as a split-plot design, with main plots each individual pig and sub-plots each day. The liveweight gain and feed intake for each day of the six-day period are illustrated in Figure 4.5 for the F pigs and in Figure 4.6 for the T pigs., The mean values for the three days on feed H and the three days on L are in Table 4.6. For the F pigs, the liveweight gain on the days when H was given was 1.85 times as great as when L was given, with no appreciable effect on feed intake. For the T pigs liveweight gain was only 1.08 as great, but the effect on feed intake was significant (they consumed 231 g/day more when they had access to L rather than H). Therefore, the interaction between treatment given previously (F or T pigs) and the feed given for the three days of this period was highly significant for both liveweight gain ($p<0.001$) and feed intake ($p<0.001$). Interactions with sex were not significant.

**(iii) Body composition at the end of the Period of Experience**

Because of the effects of the daily changes in diet composition on liveweight gain during the experience period, (F pigs grew very fast when they had access to feed H), F pigs had a slightly greater liveweight (and consequently greater EBW) than T pigs, at the end of this period. These differences, however, were not statistically significant.

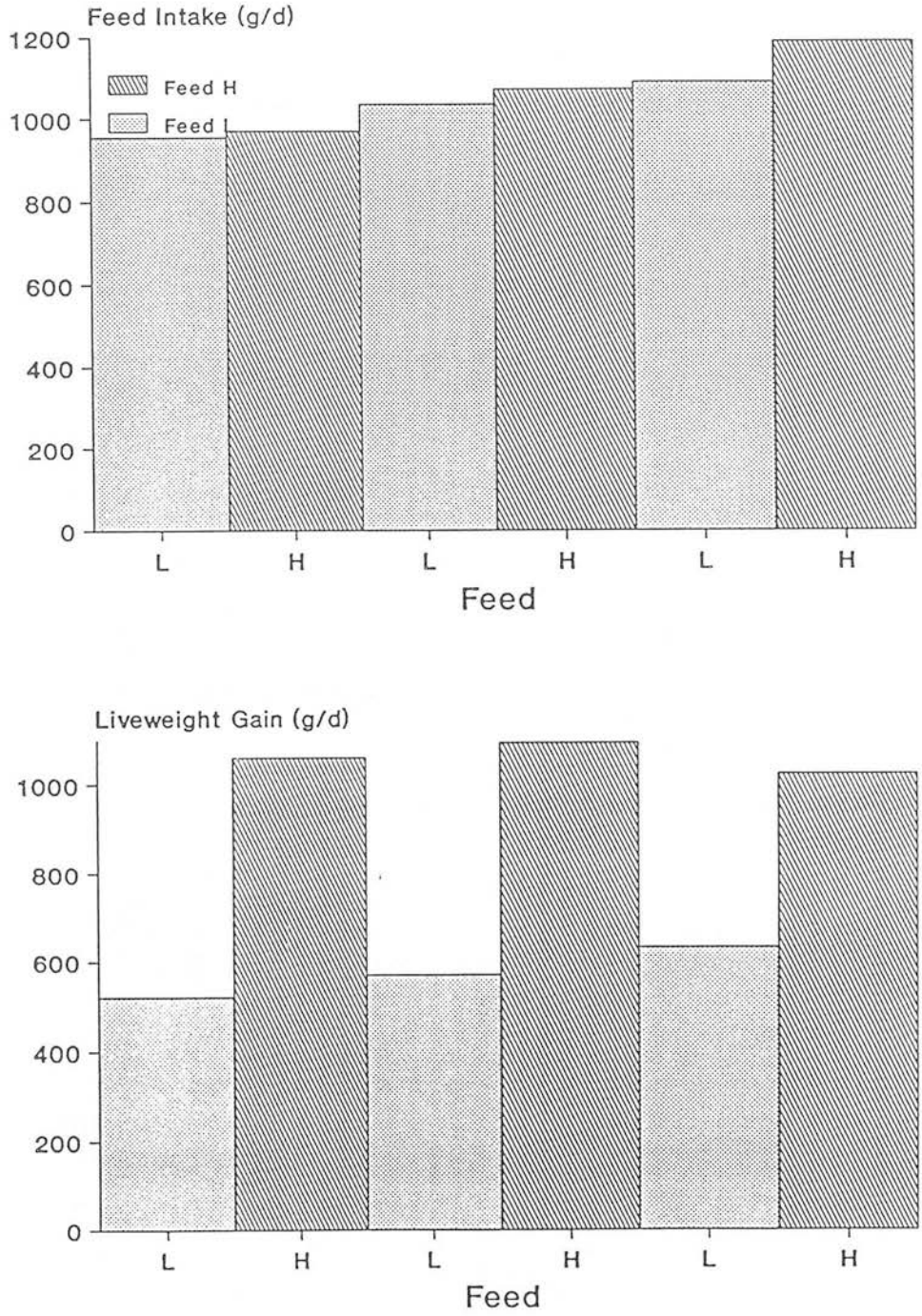



Figure 4.5 The liveweight gains and feed intakes for each day of the six-day period for F pigs eating a high (H) or a low (L) protein feed.

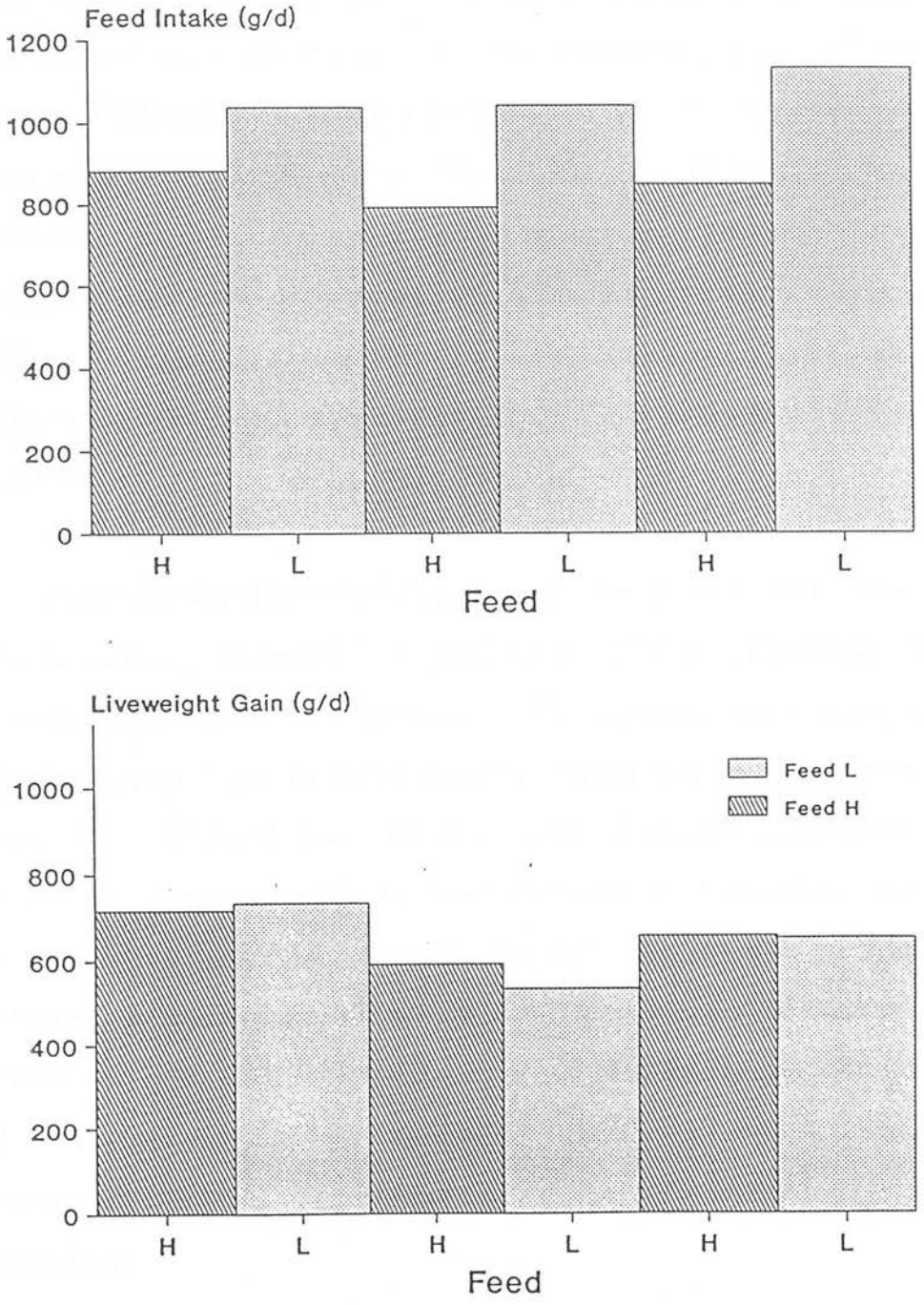



Figure 4.6 The liveweight gain and feed intakes for each day of the six-day period for T pigs eating a high (H) or a low (L) protein feed.

Table 4.7 summarises the effect of treatment (level of crude protein in the feed) during Period A (including the period of experience) on the empty body compositions of the F and T pigs. As it was expected F pigs had a higher lipid content at 18.28 kg EBW than T pigs at 17.52 kg EBW. F pigs also contained less protein and water in their empty bodies. All these differences were highly significant (at least at $p<0.01$) and there were no significant differences between the two sexes. Interactions between treatment x sex were also inappreciable and not significant. Finally, there were not any significant effects of treatment on the weights of the empty gastrointestinal tract (stomach plus guts) and the liver of the F and T pigs.

**(iv) Period B : End of Period of Experience (19.4 or 18.6 kg LWT) - 33 kg LWT**

From the statistical comparisons between FLH and TLH pigs, one female FLH pig was excluded as atypical due to poor health. This pig had a very slow rate of daily feed intake and consequently a slow rate of liveweight gain, which was even below the growth rate of the FL pigs. The compositions of the initial slaughter group of pigs (weight of component per kg liveweight) were used to estimate the initial component quantities of the choice-fed animals. Subsequently, the gain in a component was measured by calculating the difference between the final and initial component weights. The observed daily rates of feed intakes were not compared with the predictions of the Feed Intake Model (with the exception of the pigs given access to feed L only), since this model does not predict the rate of feed intake after realimentation.

**(a) Choice-fed pigs**

**P1A : Protein Growth Rates of pigs given a choice between L and H**

FLH pigs had significantly higher daily protein gains than TLH pigs ($p<0.01$). Although female pigs tended to have slower daily rates of protein gain than males, in both treatments, the difference was not significant. The means of the two

TABLE 4.7 **The effect of treatment (level of crude protein in the feed) on the empty body composition (g/kg EBW)of pigs at the end of the experience period, (n = 4).**

| | F | T | s.e.d | significance |
|---|---|---|---|---|
| LWT (g) | 19410 | 18620 | 421 | n.s. |
| EBW (g) | 18275 | 17515 | 365 | n.s. |
| Protein (g/kg EBW) | 149 | 160 | 1 | p<0.001 |
| Lipid (g/kg EBW) | 163 | 110 | 8 | p<0.01 |
| Water (g/kg EBW) | 645 | 686 | 5 | p<0.01 |
| Ash (g/kg EBW) | 30 | 29 | 2 | n.s. |
| Gross energy (MJ/kg EBW) | 9.86 | 8.08 | 0.32 | p<0.01 |
| Gastrointestinal tract weight (g) | 1520 | 1460 | - | n.s. |
| Liver weight (g) | 670 | 725 | - | n.s. |

treatments, without accounting for sex, were 170 and 133 (s.e.d. 12) g protein per day, for the FLH and TLH pigs respectively.

The B growth rate parameter was calculated by transforming (transformed degrees of maturity, Chapter I) the estimated initial and known final protein weights and dividing their difference by the known time to slaughter. The mature protein weights ($P_m$) were taken to be 45 kg for the males and 40 kg for the females (Chapter I; Yang *et al*, 1988). The B value calculated for the TLH pigs was 0.0142 (s.e. 0.0006) per day which was similar to the expected value of 0.01395 per day from Chapter I. However, the B value for the FLH pigs was much higher (0.0185, s.e. 0.0010) per day than the value for the TLH pigs and the expected value of 0.01395 per day ($p<0.001$). Therefore the proposition (P1A) that realimented pigs would resume the rate of growth known to be their potential had to be rejected.

**P2A : Lipid Gain of pigs given a choice between L and H**

At the start of Period B, FLH pigs had significantly ($p<0.001$) more lipid than TLH pigs (Table 4.8). At the end of Period B these differences in lipid weights, at the same protein weights, were markedly reduced and were no longer significant. However, because of the considerable variation in the fattening characteristics of the individual pigs, the reduction in the difference of the lipid weights of the two treatments was not significant. Females pigs had higher final lipid weight than male pigs in both treatments ($p<0.001$). This was due to the higher lipid content of the liveweight gain of the females (172 g of lipd per kg liveweight gain) than males (69 g/kg) (s.e.d. 23.8; $p<0.01$).

**P3A-P4A : Diet Selection of pigs given a choice between L and H**

The diets selected by each pig, given a choice between feeds L and H in Period B, are illustrated in Figure 4.7. In this figure the differences between the daily rate of the one feed and the daily rate of the other feed (H-L) was plotted against the total

TABLE 4.8 The lipid content of the liveweight (kg) in F and T pigs at 19.4 or 18.6 kg and at 33 kg LWT

| Liveweight | Sex | Lipid content (kg) F | T | Difference (s.e.d.) |
|---|---|---|---|---|
| 19.4 or 18.6 kg | males | 3.18 | 2.05 | |
| | females | 3.40 | 2.14 | |
| | both | 3.29 | 2.09 | 1.20 (0.03)*** |
| 33 kg | males | 3.80 | 3.57 | |
| | females | 5.59 | 5.21 | |
| | both | 4.70 | 4.39 | 0.31 (0.53) n.s. |

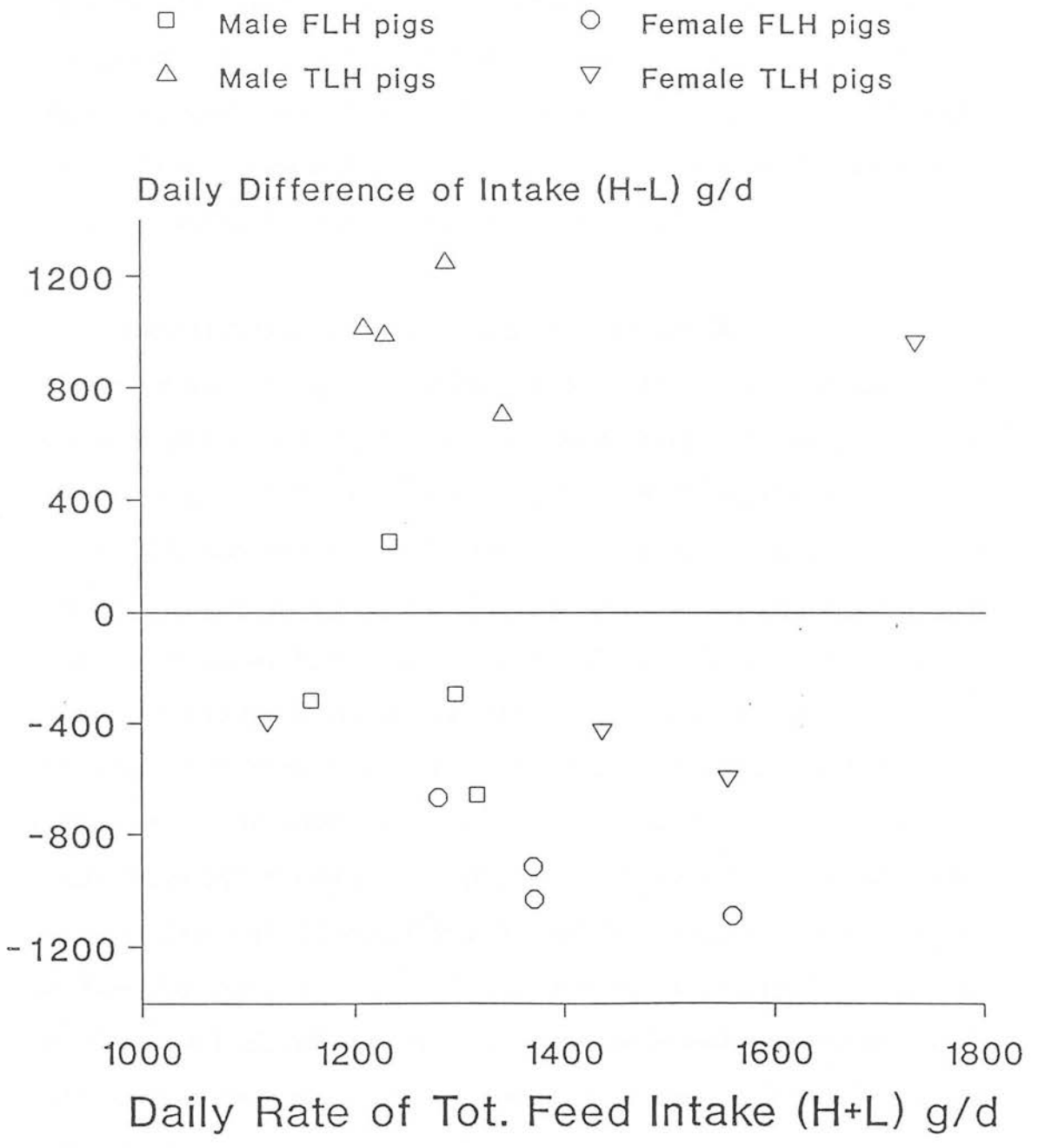



Figure 4.7 The diets selected by pigs given a choice between feeds L and H during Period B.

daily rate of feed intake (H+L). The prop.H selected by the pigs differed substantially between treatments and sexes (Table 4.9). The mean prop.H chosen was higher for the FLH than TLH pigs ($p<0.001$), and for the males than the females ($p<0.001$). The interactions between sex x treatment were inappreciable and not significant. Consequently, the CP in the diet selected was 263 vs. 203 g CP/kg fresh feed ($p<0.001$) for FLH and TLH pigs, and 193 vs. 159 g/kg ($p<0.001$) for the males and females respectively. Therefore the propositions that FLH pigs would select a diet of a higher protein content thant TLH (P4) and males pigs would select a diet of a higher protein content than females (P5) were supported.

**P5A Liveweight Gain of pigs given a choice between L and H.**

The rate of liveweight gain can be seen in Figure 4.8, where the average rate of liveweight gain in each day for the FLH and TLH pigs was plotted against the liveweight at the start of the day. An increased rate of liveweight gain was observed for the FLH pigs, especially during the first five days of Period B, which was contrary to the expectations that FLH pigs would grow at slower rates than TLH pigs. To account for the changes in the rate of liveweight gain over time, Period B was divided into two sub-periods: Period B1 (from 20.5 to 26.5 kg liveweight) and B2 (from 26.5 to 33 kg liveweight). FLH pigs gained liveweight at an average of 1055 g per day in Period B1, a rate which was significantly higher (s.e.d. 60; $p<0.001$) than that of TLH pigs of 764 g/day. In Period B2, although there was a decline in the rate of FLH pigs (1006 g/day) and, as expected, an increase in the rate of TLH pigs (819 g/day), the difference between the two treatments was still significant (s.e.d. 53; $p<0.01$). Male and female pigs in each treatment had similar rates of liveweight gain and the interaction between treatment x sex was inappreciable.

TABLE 4.9 The effect of treatment and sex on the proportion of the Total Feed Intake (TFI) taken as Feed H (prop.H, g/kg TFI)

| | Prop.H (g/kg TFI) | | |
|---|---|---|---|
| | F | T | Both |
| Males | 893 (47) | 405 (73) | 649 (100) |
| Females | 478 (150) | 169 (25) | 301 (85) |
| Both | 715 (104) | 287 (57) | |

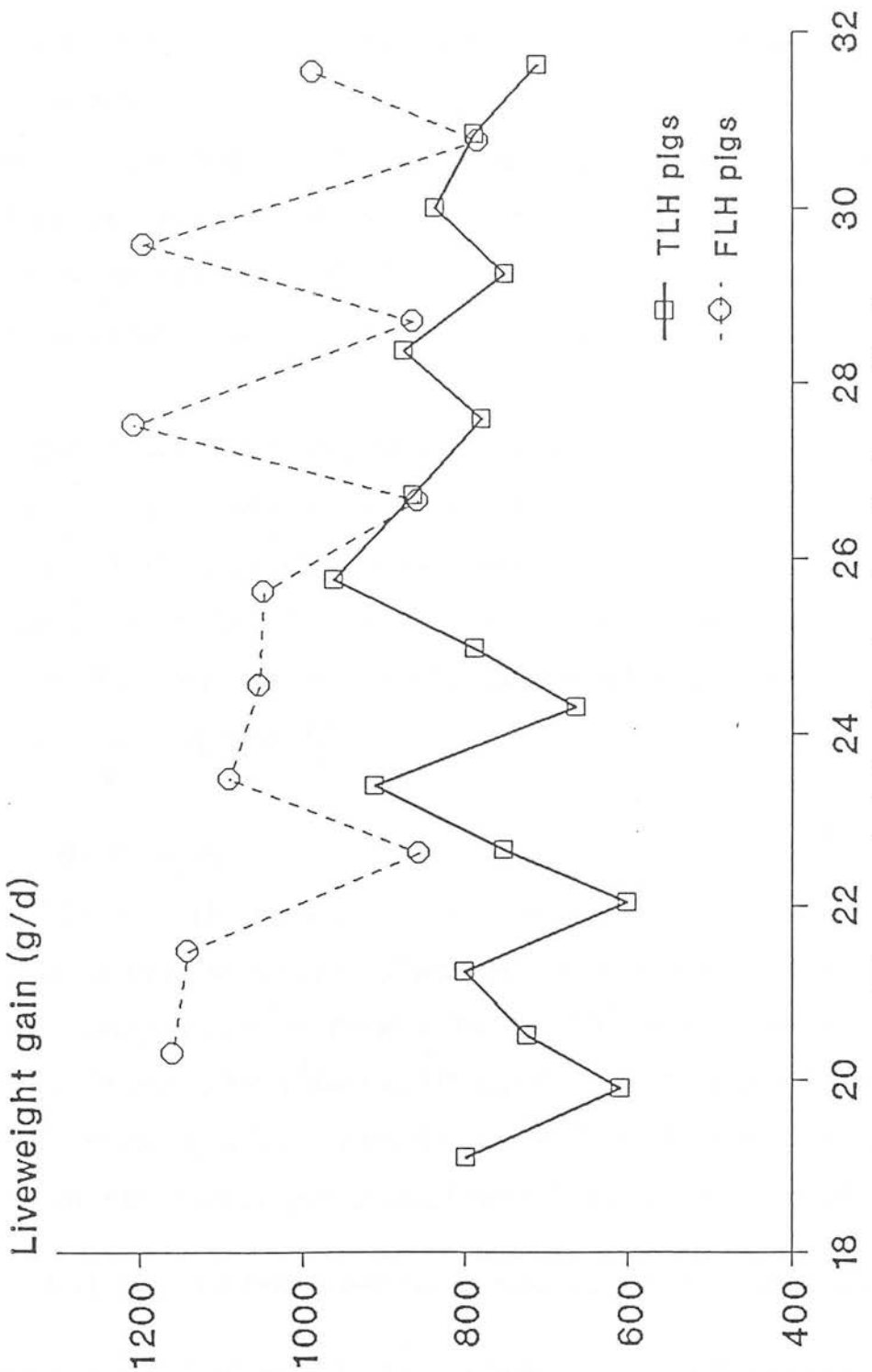



Figure 4.8 The rate of daily liveweight gain by FLH and TLH pigs during Period B.

**Feed intake and Feed Conversion Efficiencies (g gain per g feed) of pigs given a choice between L and H**

The average daily total feed intake (TFI) for both treatments, during Period B, is presented in Figure 4.9. The rate of TFI was similar for both treatments, but there was a significant effect of sex on the rate of TFI, with females consuming substantially more feed than males. The rates of TFI eaten by the FLH pigs were 1266 and 1574 g/day for the males and females respectively, and 1244 and 1394 g/day for the male and female TLH pigs respectively (s.e.d. 50; $p<0.001$). The interactions between treatment x sex were inappreciable and not significant.

FCE also differed significantly between the two treatments and the sexes, in accordance with the reported differences in liveweight gain and feed intake. For example, FLH pigs continued to convert feed more efficiency than TLH pigs in both sub-periods B1 and B2, the difference being more marked in Period B1 (0.780 vs. 0.601; $p<0.01$). This was a reflection of the decrease in the rate of liveweight gain of the FLH pigs during Period B2.

**(b) Single-fed pigs**

**P2B : Liveweight gain of pigs given access to feed H**

Similarly to the choice-fed pigs, FH pigs had a higher rate of liveweight gain than TH pigs during the start of Period B (Figure 4.10). However, the rates of gain between FH pigs of 959 g/day and TH pigs of 841 g/day were not significantly different (s.e.d. 97; $p>0.25$). When the rates of liveweight gain of FH pigs were compared to those of FLH pigs, no significant difference could be detected.

**P1B : Feed Intake and Feed Conversion Efficiencies of pigs given access to feed H**

The average daily feed intakes for both treatments (FH and TH) during Period B are illustrated in Figure 4.11. The expectation (P1B) that previously limited pigs would have a reduced daily rate of feed intake, compared with TH pigs, was not

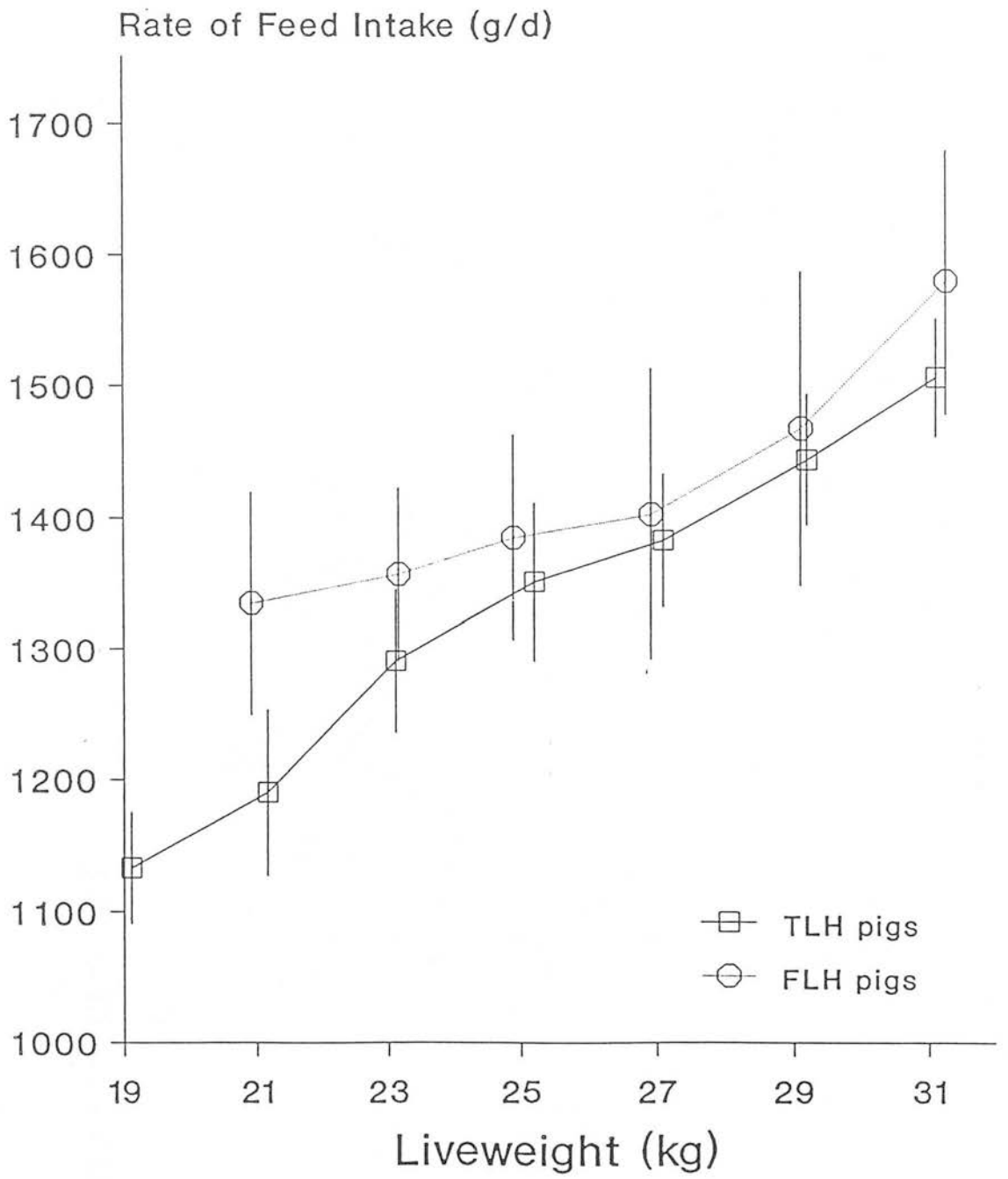



Figure 4.9 The rate of total feed intake of the choice-fed FLH and TLH pigs during Period B.

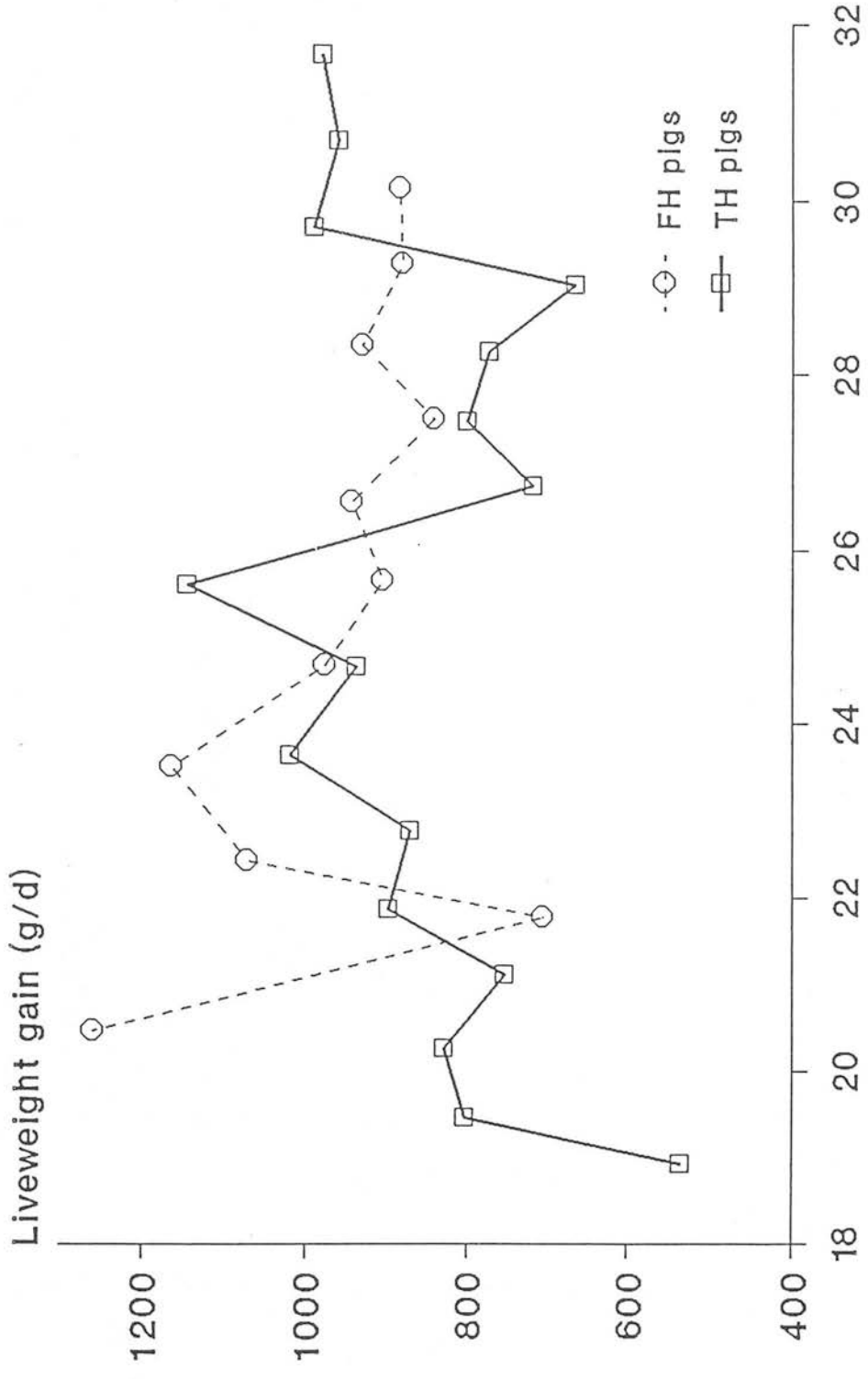



Figure 4.10 The rate of daily liveweight gain by FH and TH pigs during Period B.

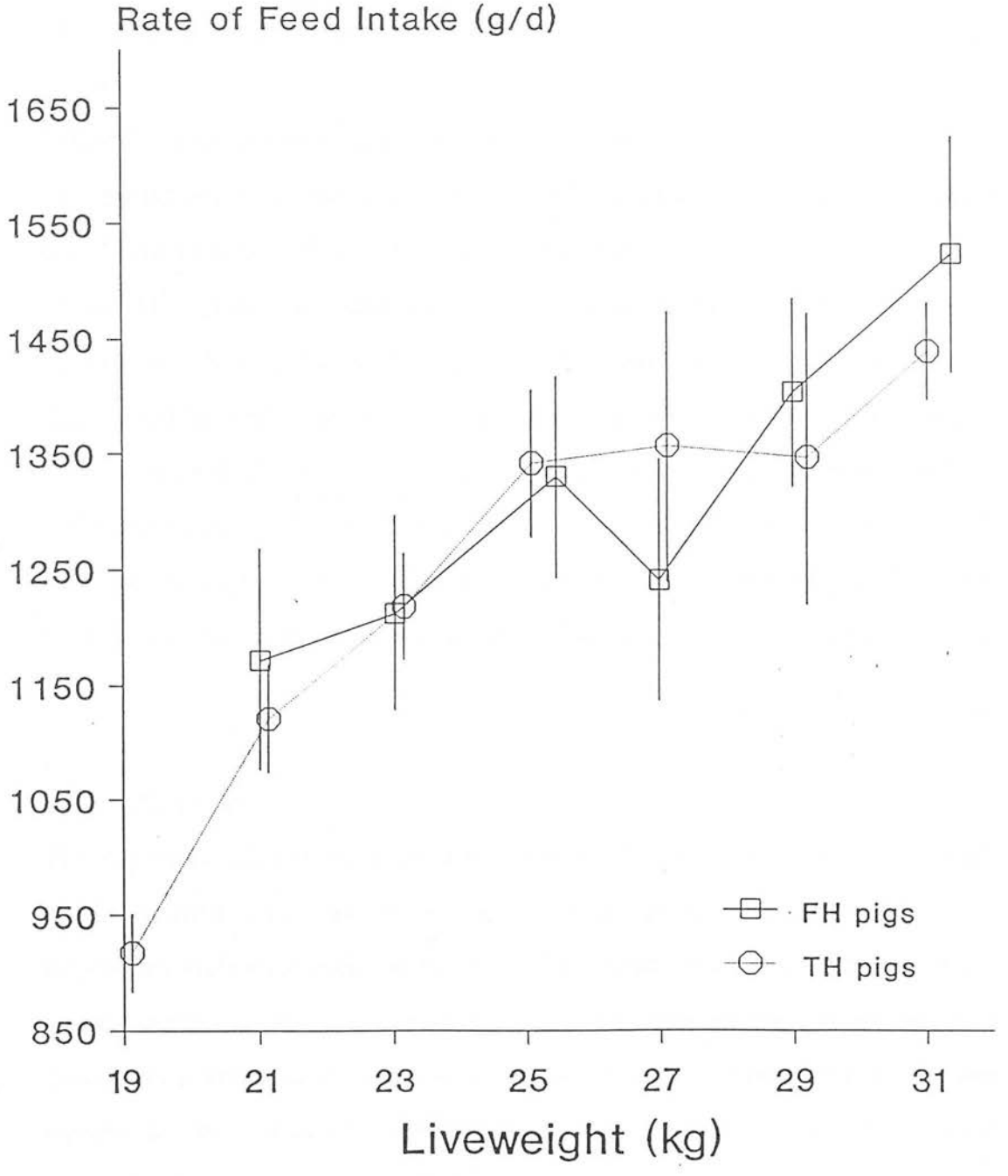



Figure 4.11 The rate of feed intake of FH and TH pigs during Period B.

substantiated by the similar rates of feed intake between the two treatments in Period B (1329 vs. 1252 g/day; s.e.d. 98). The FCE values were also not significantly different between the two treatments (0.718 vs. 0.671; s.e.d. 0.028, for the FH and TH pigs respectively), in accordance with the reported differences in the rate of feed intakes and liveweight gains.

**P1C-P2C : Performance of pigs given access to feed L**

As expected pigs given access to feed L only during Period B performed in a similar way, irrespective of their treatment during Period A (F or T pigs). Therefore, both FL and TL pigs grew at a slow rate, since they were limited by their protein intake; their rates of liveweight gain being 666 and 673 g /day (s.e.d. 32) respectively. They also had similar daily rates of feed intake (1398 vs. 1455 (s.e.d. 66), for the FL and TL pigs respectively), but their FCE values were significantly different (0.476 vs. 0.462 respectively; s.e.d. 0.0004; $p<0.05$). The observed rates of FI were not different from the values predicted by the Feed Intake Model, for pigs of this liveweight range, given free and continuous access to feed L at an ambient temperature of $16^{o}C$.

### 4.5.5 Discussion

The experiment gives strong support to the theory that the diet selected by each pig met its apparent requirement to the time and state. Therefore, pigs delayed in their growth and made excessively fat by being given access to a low protein feed in one period, selected a diet in a subsequent period that enabled them to resume their growth and restore their desired level of fatness. However, some of the propositions asserted by the theory of growth recovery earlier in this chapter have to be reconsidered in respect of the findings of this experiment.

**Compensatory protein growth**

It was proposed that FLH and FL pigs would resume their protein growth rate in Period B, at the same rate as their TLH and TH counterparts; this rate of growth would be that of their potential. This view is illustrated in Figure 4.12(a), where limited and non-limited animals have parallel rates of protein growth after the restoration of the non-limiting conditions. Therefore, the time lost in protein growth ( $\Delta$t) by the limited animals can never be recovered.

However, the results demonstrated that FLH (and presumably FH) pigs had an accelerated protein growth rate, which was much higher than their expected potential. This protein growth rate was also higher than the estimates of the protein daily gains for pigs of the same degrees of maturity from grandparent stock of the leading breeding companies in the UK (Whittemore, 1983; MLC, 1975-1984). Such an increase in protein growth rates, however, could not be attributed in the restitution of the feed processing organs as it was attributed in the experiments of Tullis (1981) and Stamataris *et al* (1985), since in the current experiment there were no apparent differences in the weights of these organs between F and T pigs.

It seems, therefore, necessary that the strict position that F pigs would resume protein growth rate at the same rate as T pigs, needs to be rejected. Limited or restricted pigs are able to grow protein at rates faster than their potential, after the restoration of the non-limiting conditions. This suggestion, presented in Figure 4.12(b), implies that the time lost in protein growth ( $\Delta$ t) can be regained, at least to a certain extent. For Emmans and Fisher (1986) the units of potential growth were represented by a chemical (X). Units not turned into actual growth during limiting conditions could cause an accumulation of (X) which decayed at some fractional rate (f). On this model, there was a store of (X) at the end of the period of limitation which could be subsequently turned into actual growth and hence, the time lost in

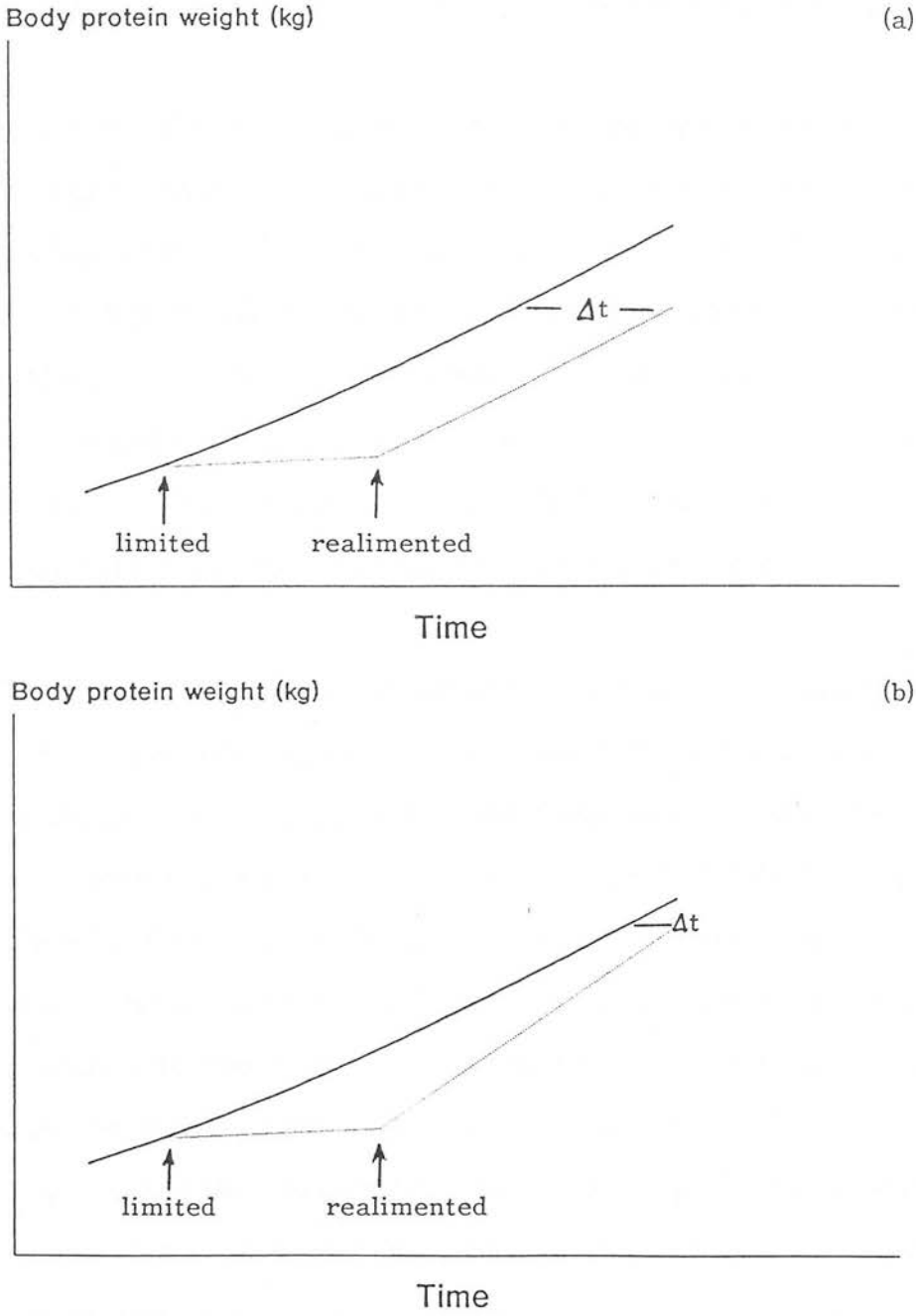



Figure 4.12 (a,b) Growth of protein following a period of limitation. (a) No recovery after realimentation. (b) Partial recovery after realimentation.

protein growth ( $\Delta$ t) reduced. If, in the limit, (f) was zero, $\Delta$ t could be reduced to zero over time; if (f) was positive, only some of $\Delta$ t could be offset over time.

The idea that some time lost in protein growth could be regained was substantiated by the findings of Stamataris *et al* (1986), who gave fat animals free and continuous access to a high protein:energy feed. The ( $\Delta$ t) in protein weight of 12.9 days was reduced to 7.2 days; the continuation of their experiment showed that the remaining delay could not have been any further reduced. Similarly, in our experiment FLH and FH pigs gained weight (and therefore protein weight) at a faster rate than TLH and TH pigs, only during the early part of Period B. The weight gain by LWT curves, suggested that the remaining delay could not be further reduced.

Tullis (1981) suggested the part of the body protein undergoing compensation was the depleted labile protein reserves, whose repletion resulted in these acceleratory protein gains and the same was suggested by Wallace (1959) and Holt, Halac and Kajdi (1962). The latter authors conceived the protein stores not as inert depots (like the adipose tissue for fat or the liver for glycogen) but as an integral part of organised living tissue. The possible site of these depots was suggested to be the protein (skeletal) muscle (Millward, Garlick, James, Nnanyelugo and Ryat, 1973; Millward, Nnanyelugo and Garlick, 1974, 1975), since an increased protein synthesis was observed there during the realimentation period. This suggestion implies that once the protein stores have been repleted, compensation ceases and the animal will continue growing on the path set by its inheritance.

**The effect on Feed Intake**

It was expected that FLH and FH pigs would have a decreased rate of feed intake, when compared with T pigs, in order to restore their lipid:protein ratio. This expectation was based on the assumption that F and T pigs would have the same requirement for protein growth, since they were expected to grow protein at a similar

rate (that of their potential). However, since FLH and FH pigs were able to grow protein at rates higher than their estimated potential, the two propositions had to be reconsidered.

**P3A:** The FLH pigs will select a diet of a much higher protein content than TLH pigs, to satisfy (a) the increased protein requirements for protein growth and (b) restore the desired lipid:protein ratio in their empty body.

**P3B:** The FH pigs will have a higher rate of intake than TH pigs, in order to satisfy their increased protein requirement and replenish their protein body stores.

Here, it is necessary to stress the importance of the realimentating conditions (feed protein content and ambient temperature), if maximum compensatory protein growth is to be observed. It is possible that such an opportunity was not given to all FLH pigs by Feed H (which contained 278 g CP/kg of feed). Some FLH pigs were able to meet their requirements by selecting only feed H and increasing their rate of feed intake. This suggestion is substantiated by the diets selected by the male FLH pigs: prop. H selected was 1000 g/kg TF1 during the first days of Period B. When Stamataris *et al* (1986) gave fat pigs *ad libitum* access to a high (H) or a very high protein feed (VH), they did not observe markedly increased compensatory protein gains. They suggested that this was due to the high ambient temperature and consequently lower feed intakes. Their suggestion was supported by the poorer performances of the fat animals on the VH than the ones on the H feed. A similar explanation could account for the complete absence of compensatory protein gains in an experiment by Ratcliffe and Fowler (1983). Their fat pigs were given access to a 'standard diet' which probably meant a feed with moderate protein content. Therefore, the lack of compensation was due to insufficient protein intakes which were provided by this 'standard diet' at the temperatures used.

It is possible that some (if not all) T pigs had a reduced lipid:protein ratio at the end of Period A. The slow lipid gains on feed H, at certain temperatures, has been discussed in Chapter III. Therefore, T pigs had a higher requirement for energy, in order to replenish their desired body fatness, which was achieved by an increase in feed intake. This increase exactly offset the increase in feed intake (in order to achieve high protein intakes) by F pigs. This suggestion could account for the similar feed intakes between FH and TH pigs in Period B.

**Body fatness and the difference between the sexes**

The expectation that FLH pigs would reduced their lipid:protein ratio to the same lipid:protein ratio of the empty body of the TLH pigs was fulfilled, since both treatments had similar lipid weights at 33 kg LWT. However, the magnitude of the difference between the lipid gains of the male and the female pigs - although in the right direction - was unexpected. This problem appeared to be two-fold.

(a) T pigs reached the initial slaughter weight (at 19.4 kg liveweight) having a lipid:protein ratio lower than the desired. If so, it is likely that females were more diverted from their desired level of fatness than males. Subsequently, when TLH pigs were offered the choice, females chose a diet with a lower protein content and had a higher feed intake than male TLH pigs. This combination enabled them to grow at the rate set by their inheritance and at the same time restore their lipid:protein ratio by gaining extra lipid.

(b) The above suggestions can account for a small part of the large differences in the body composition of the male and female pigs in the FLH treatment. However, it has been shown that sexes respond differently to restriction and realimentation (Williams and Hughes, 1975; Widdowson, 1976). For example, in response to feed restriction, young female rats lost more lipid and less protein than young male rats (Widdowson, 1976). If such a difference in the

response to restriction and realimentation exists, it is possible then that female pigs are able to correct their fatness at a much lower rate than males.

**The effects of the change from a high to a low protein feed**

It is possible that an animal accustomed to a high protein diet arrives at a relative fixed high rate of protein catabolism and may continue to break down body protein at a fast rate, even after the level of protein in the diet has been lowered (Holt *et al*, 1962). This could be more pronounced if the animal was fed on the high protein diet for a long period (Tullis, 1981).

It has been suggested that pigs fed on high protein diets developed correspondingly greater rates of protein turnover, and were less successful in coping with the immediate effects of protein deprivation (Vaughan, Filer and Churella, 1962). However, the duration of such a high rate of protein catabolism has been reported to vary for pigs, from a few days (Tullis, 1981) up to a hundred days (Vaughan *et al*, 1962), and a strong criticism has been directed against the experimental techniques used by the latter investigators.

The above suggestion implies that pigs diverted from a high to a low protein feed (pigs TL) will perform worse than pigs fed on a low protein feed throughout (pigs FL). This will be the direct effect of their high protein catabolism, which will result in negative or marginally positive retention (Tullis, 1981). However, when T pigs were given feed L, they did not show any sign of less successful coping with this feed and their performance was identical to their FL counterparts. The argument that TL pigs had the chance to adapt their catabolism on feed L during the short period of experience, is opposed by the performance of these pigs when they had access to feed L during that period, which was not different from the performance of the F pigs.

**The effect of alternating high and low protein feed on feed intake and growth rates**

It has been established that when 'normal' pigs (previously fed on a high quality commercial feed) were offered feed L and H alone on alternate days, they consumed more feed when they had access to L rather than H. Such evidence is derived from:

(a) Experiment 3, where pigs were offered feeds L and H on alternate days, for a period of 36 days (n = 4) (Figure 3.5.1).

(b) Experiment 3, where pigs were offered feeds L and H on alternate days, for a period of 6 days, as part of their learning. This treatment was repeated twice; once at the beginning of the experiment and then 12 days later (n = 6) (Figure 4.13).

(c) Experiment 4, where pigs were offered feeds L and H on alternate days (n = 4) and feeds L and B on alternate days (n = 4).

In cases b and c, the difference in feed intake, although evident, was not statistically significant. A pig could refuse to consume either of the two feeds presented on the first day of the 6 day period and this had a substantial effect on the statistical comparison.

The increased intake on L rather than H, was similarly observed with the T pigs of this experiment. The increased differences between the rates of intake of L and H here, may reflect the difference in the ambient temperatures used (16$^{o}$C for this experiment, 22-24$^{o}$C for the rest). However, when F pigs were given a similar treatment, the difference in the intakes between L and H was not apparent any more. This was due to an increased rate of intake on H, up to the rate of L. This increase could be then explained by the accompanying growth rates of the animals. F pigs grew at 1061 g/d on feed H, which represented a difference of 406 g/d from the growth rates of the T animals on the same feed. Therefore, the increased intake on

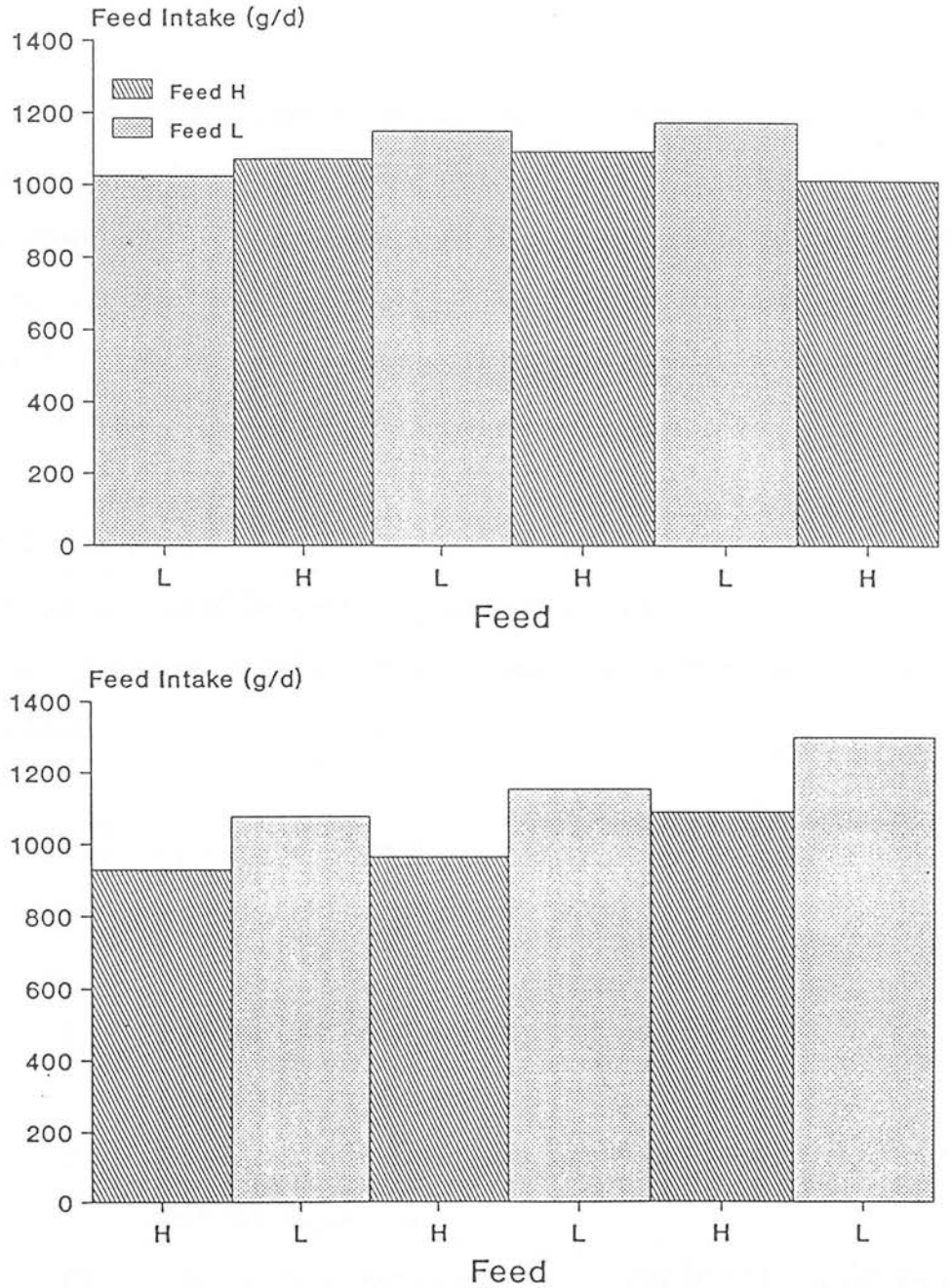



Figure 4.13 The liveweight gains and feed intakes for each day of the six-day period of experience for pigs given access to feeds L and H on alternate days (n = 3).

H for the F pigs represented their desire to resume their growth plan and replenish their empty protein stores (compensatory protein growth).

The response from the consumption of feed H appeared to be virtually immediate and, as judged by the daily feed intakes, was unlikely to reflect differences in gut fill. Such rapid changes in growth rate of such size imply that the metabolism of young pigs is extremely active, with a rapid rate of responses to changes in the protein of the diet, which allows extra protein eaten to be effectively used for growth.

### 4.5.6 Conclusions

The extended test of the theory of diet selection and the reassessed theory of growth recovery, as it was elaborated in the discussion, have given sufficient evidence to conclude:

(i) that pigs, when given the opportunity to recover on a set of feeds after a period of feeding on a limiting feed,

  (a) show an accelerated rate of protein gain, which is well above their potential rate for their genotype,
  (b) may restore their lipid:protein ratio in their empty body, to that set by their inheritance,
  (c) select a diet, between the feeds, that satisfies their requirements for an accelerated rate of protein gain and slow rate of lipid gain,
  (d) select a diet which meets the different growing and fattening requirements by the two sexes.

(ii) that pigs, when realimented on a high protein feed after a period of feeding on a limiting feed

(a) show an accelerated rate of liveweight gain, which is above their potential rate of liveweight gain for their genotype. This accelerated liveweight gain is the result of an accelerated protein gain (compensatory protein gain),

(b) may try to restore their lipid:protein ratio in their empty body to that set by their inheritance (by growing lipid at a lower rate).

(c) eat the high protein feed at a rate which satisfies their requirements for maintenance, accelerated protein growth and slow lipid gain.

# CHAPTER V

## GENERAL DISCUSSION

*Rome*

## 5.1 THE DESCRIPTION OF THE POTENTIAL GROWTH OF A PIG

In this thesis an attempt has been made to develop a general theory of the growth and feed intake of the pig. Data from experiments conducted under conditions which satisfied the requirements of the theory, or from existing published experiments, have been compared with the predictions of the theory. Such an interplay between theory and experimentation led to the formulation of an empirical description of the expected potential growth of the pig in Chapter I.

It was suggested that a pig (or an animal in general) inherits a potential rate for remainder growth (defined as protein plus ash growth), which is closely associated with strict ratios of water and lipid to the remainder. The observed lipid:protein (or remainder) ratio exhibited under non-limiting conditions was called the desired level of fatness. The first part of this empirical description, the idea of an inherited upper limit to remainder growth, is a generally accepted one, at least as a potential for protein growth. Arguments arise only for the description of the rate of change of the potential protein growth over time (eg. Whittemore, 1976; Kielanowski, 1969). Whittemore (1976) suggested that an upper limit to daily protein retention is attained at 20 kg and maintained until 120 kg liveweight. Such a suggestion contrasts with the idea of describing protein growth by the Gompertz equation, which was employed in this thesis and estimates that protein growth rate reaches its maximum at 0.367 of the mature protein size.

The second part of the description of a pig, the concept of a desired level of fatness, opposes the conventional wisdom that suggests that domesticated animals are not able to 'regulate their body fatness', since they continue to gain fat when they are given access to high quality feeds, until they become very obese (Forbes, 1985). The pig has often been referred to as 'the proverbial glutton' (Braude, 1967; Forbes, 1985) and it has been suggested that selection for rapid growth, without regard for carcass

composition, has resulted in a relaxation of the control over body fatness (Forbes, 1985). It is accepted, however, that this control has been maintained in wild animals. In this thesis, it was proposed that intensive genetic selection against fatness has produced a pig with a low level of desired fatness, which could be manifested when the pig was offered non-limiting conditions to growth. Excessive fatness, above the desired level, could be observed when a pig was given access to an imbalanced feed (in terms of the protein:energy ratio) which reflected its attempt to eat for the first limiting feed resource to growth. Strong evidence for this idea was provided by the single-feeding parts of Experiments 1 to 4, and particularly by the choice-feeding part of Experiment 5. In the latter experiment pigs previously made fat by being given access to a low protein feed, selected a diet that enabled them to grow lipid at a slower rate than pigs assumed to have their desired level of fatness.

The advantages of describing a pig in terms of its potential remainder gain and desired level of fatness have been summarised by Emmans and Fisher (1986):

(i) its requirements for feed resources can be calculated

(ii) its growth and composition, given that its requirements are met, can be predicted, and

(iii) it can be sensibly compared with other animals to identify similarities and differences.

The third advantage implies that the effects of possible treatments can be predicted and choices can be made between such treatments. Emmans (1988b) emphasised the role of such a sufficient description of the animals for breeders who have to provide descriptions of their stocks to their customers, who in turn have rationally to choose between treatments.

## 5.2 THE DIET SELECTION OF PIGS

The theory of the necessary conditions for the non-limiting growth of a pig in Chapter II, suggested that these conditions may be achieved when the pig is given free and continuous access to a set of feeds as a choice. They theory asserted that a pig would choose a combination of the two (or more) feeds, which could support its potential growth and, by definition, this reflected the pig's needs. It was assumed that since animals possess the desire to fulfil their potential growth plan (an idea which derived from Aristotle) they are then expected to search amongst all the feeds on offer, until they succeed in acquiring a non-limiting diet for growth. Such an assumption implied that animals only needed the necessary feeds to choose from, a condition which was provided in Experiments 1 and 2 by offering to pigs a choice between two feeds of different protein:energy ratios, one above and one below the pig's presumed requirements.

However, the results of these two experiments suggested that there is a second condition that had to be met if the animals were to be successful in their diet selection; that is, animals must also be given the necessary chance to choose. The diets selected by the pigs in the first two experiments varied considerably between individual animals. Consequently, their performance also varied, with only some animals achieving their presumed potential rate of growth. It was then suggested that pigs which failed to select a non-limiting diet, did not have the necessary chance to choose, since their diet selection was affected by the random event of contaminating the troughs with excreta; a fact which was caused by the experimental conditions used (the position of the feeding troughs in relation to the eliminating area).

To ensure that pigs were given both the necessary choice, and chance to choose, a simple method, the 'period of experience' was introduced in the subsequent

experiments (Experiments 3 to 5). During this period pigs were given the chance to experience separately each of the two feeds, which were then offered as a choice, on alternate days and for a total period of six days. This method was supported by the idea that the control of what to eat and how much to eat can be learned (Morgan, 1894). The duration of the period was suggested by the observations on the pigs which successfully chose a non-limiting diet in Experiment 2.

Since feeds vary in their structures, odours, colours or tastes, the animal would be expected to learn to form associations between the nutrient content and the sensory qualities of the feeds, after having consumed sufficient amounts from each feed. However, it was stressed that the sensory properties of the feed will be used only as cues for diet selection, and should not be used to predict the outcome of choice-feeding experiments, as it has been wrongly suggested in the past (eg. Wood-Gush and Kare, 1966). Once the necessary associations were made, the pigs in Experiments 3, 4 and 5 were able to select a diet that: (a) reflected their requirements for maintenance, growth and fattening. (b) reflected the differences between the two sexes, and (c) was presumed to minimise the excess of protein intake.

In all the experiments reported in this thesis, pigs were offered a choice between two feeds that differed considerably in one nutritional variable (protein). However, since the theory of diet selection proposed that animals select a diet that meets their requirement for any nutrient (Chapter II), it is possible that pigs can be given, with benefit (for example, to avoid complicated feed formulations), a choice between more than two feeds. In this case, the animal will have more degrees of freedom to exercise its diet choice, and the decision of how much of each to eat would be a more complex one. The period in which the animals need to sample all the feeds, and consequently the period of experience, might need to be longer than six days.

The extension of this period then might have an importance in decisions when choice-feeding is considered as a potential feeding regime in commercial practice.

The problems of an extended period of experience could be overcome if the pigs were group housed, instead of being in single cages, in order to exploit the phenomenon of allelomimetic behaviour (Chapter III). However, with group-housed pigs it must be ensured that all animals have free and continuous access to all feeds at a time, since it is very common for pigs to compete at the trough. Considerations about space allowances (space per pig per trough) and the position of the trough in relation to the eliminating areas might then be of critical importance. When these factors have been taken into consideration in choice-feeding regimes of group-housed pigs (Gous, 1988; personal communication), it appears that all pigs in the group were successful in selecting a diet that met their requirements.

## 5.3 PRACTICAL APPLICATIONS OF CHOICE-FEEDING

It was suggested earlier that choice-feeding has two potential advantages for the pig producer:

(i) it allows pigs to reveal their inherent characteristics, which aids selection, and

(ii) it gives information about the pigs which can be used by commercial producers, so that they can accurately choose the effects of possible treatments on them.

In the past, the commercial pig producer did not always require the achievement of the pig's potential, and it has been a common practice to feed pigs on restricted scales in order to produce carcasses with a level of fatness below that desired by the pig and therefore avoid unwanted fat. However, genetic selection has produced a pig with a low level of desired fatness, and this has resulted in an increasing percentage

of pigs which are fed *ad libitum* (Webb, 1988). By 1986 the 33 per cent of the total pig population of the UK was fed on *ad libitum* or 'to appetite' regimes compared with only 20 per cent in 1979 (Riley, 1988).

In the case where the fatness desired by the pigs is not greater than that desired by the pig producer (as it might be in young pigs and, in particular, in boars), choice-feeding can be employed as a commercial feeding practice. From the other species that have successfully shown their ability to select a diet that meets their requirements, choice-feeding has been employed in the commercial avian production (eg. North of Scotland College of Agriculture). The advantages of using such a commercial feeding system in poultry have been summarised as follows:

(a) Choice-feeding reduces feeding costs. Instead of using ground cereals, mixed with other feeding ingredients, the avian species can be given a choice between a whole unground cereal and a balancer. Thus costs of feed mixing can be considerably reduced, and when the producer has access to a locally produced cereal then transport can be also considerably reduced.

(b) No further feed changes are needed. The feed supplied to the birds must change as the nutrients requirements of a flock change with time. The more frequent the changes, the more exactly the requirements can be matched. However, since producing and handling a large number of feeds results in increased feeding costs, there is inevitably a compromise between matching the flock's requirement and the number of feeds produced. Choice-feeding can then successfully be employed, since the same balancer can be used throughout the growing period.

(c) Separate sex feeding is not necessary. Within a mixed-sex, choice-feeding flock, the males and females are able to select different diets which reflect the different requirements by the sexes.

Advantages (b) and (c) can also apply in the case of commercial choice-feeding of pigs, since the commercial pig production uses the feeding of a feed for a considerable amount of time (usually three feeds for the entire pig's growing phase), thus treating the average pig by ignoring differences between genotypes and sexes. Advantage (a) could have only small reference to pigs. However, a considerably amount of research may be needed to focus on the economics of applying choice-feeding in commercial practice. The costs of replacing equipment, or the conversion of existing feeding troughs, the handling of two feeds (eg. a separate feed delivery system) and other technical issues must be considered in relation to the financial benefits, when choice-feeding of pigs will be commercially adopted. In poultry, analogous research which has evaluated the cost benefits of such adoption (eg. Tauson and Elwinger, 1986) has suggested that there is considerable financial benefit by the use of choice-feeding in commercial practice.

## 5.4 POSSIBLE MECHANISMS UNDERLYING DIET SELECTION

The manifestation of the ability of pigs to select a diet that supported their potential rate of growth opens the question of the physiological mechanism which underlies diet selection. It seems more logical first to establish whether such a biological strategy exists, and that the diet selection of pigs is rational and systematic rather than capricious and random, before suggesting any monitoring and guiding processes. However, biologists have often proposed theories of diet selection mechanisms, before having established its occurrence (eg. Lat, 1967). Such a misconception has often led to confusion that individual animals varied between a 'glucogenic' and 'gluconeogenic' types of nutrient intake, with patterns of intake being 'remarkably

stable in any one animal'. Therefore, the differences in the ability of animals to choose successfully a diet that met their requirements depended on the capricious selection of the sub-types of animals (Blundell and Hill, 1987).

The approach which was adopted in this thesis focussed on the 'purpose' of animals: to grow protein at their potential and achieve their desired level of fatness. This suggestion, for the purpose of the thesis, was sufficient to explain the consumption of a freely available feed. However, the question as to whether the non-random consumption of protein (or other nutrients) is subject to the influence of a number of mechanisms or a unique process has been the subject of considerable argument. The supporters of the single-mechanism assumption propose that a signal from the blood to the brain (eg. the proportion of tryptophan to large amino acid concentration) which activates the synthesis of a substance in the brain (eg. serotonin), is responsible for diet selection of protein or carbohydrates (Fernstrom, 1987; Peters and Harper, 1987). The opposing group suggests that it seems unlikely that a single mechanism will be responsible for diet selection, and possibly diet selection involves both unconditioned and conditioned processes (Blundell and Hill, 1987). The latter theory also proposes that there is not such a concept as protein intake regulation, since such an idea implies a fixed value for the intake of protein to which all animals must conform via a sort of biological legislation. The mechanism guiding control of protein intake may not be aimed at preserving protein intake at a particular set value, but rather to keep protein intake within an upper and a lower limit. The avoidance of very low or very high protein intakes could be managed by the mechanisms of feed-aversion (or poisoning avoidance) (Rozin, 1967) which were detailed in Chapter III.

Evidence for the absence of accurate protein intake regulation was derived from experiments on rats which were given a choice between feeds of different protein contents (eg. Leathwood and Ashley, 1983a). In these experiments the diets selected

varied considerably between individuals, but they were characterised by the stability of the choice of an individual; rats were selecting diets which varied from 13 to 40 per cent crude protein content (Lat, 1967; Overmann, 1976; Leathwood and Ashley, 1983a). On the basis of these results, Booth (1985, 1987) suggested that instead of looking for a set-point, it is more useful to look for a feed-back mechanism that would regulate protein intake. Such a mechanism would help to correct downward deviations of a particular nutrient, and resist upward deviations.

However, the results of the experiments reported in this thesis do not support the theory that protein intake regulation operates within an upper and a lower limit. Such a suggestion opposes the concept of evolutionary fitness and implies that animals are not always successful in selecting a diet that supports their potential rate of growth and avoid excess of protein intake. Pigs in Experiments 3 and 4 consumed a diet that did not vary much between pigs of similar state and they changed the dietary protein content as they grew. Although it is appreciated that the paths of diet selection of every pig will differ in magnitude since they reflect the pigs' genotype and sex, it is suggested that the paths of diet selection of pigs of similar state at a time will lie on a universal curve of a form common to that of pigs in Experiments 3 and 4.

Booth (1987) has also suggested that 'cue-consequence' learning (unconditioned pathway) can wholly account for diet selection. This explanation cannot, however, account for the rapid decline in the crude protein content of the diet selected, nor for the rapid change in the rate of feed intake when the crude protein content of the feed was alternated daily (pre-experimental period, Experiment 5). Conditioned pathways can wholly account for the behaviour of animals in an environment with predictable components, that is where the relationship between the cue and the consequence remains stable (Staddon, 1983). It has been established, in Experiment 3, that pigs first need to obtain information about their feeds in order to be

successful in their diet selection. However, once the conditioned pathways have been established (ie. the pigs recognise the feeds from their sensory properties) other, unconditioned pathways must be involved which could account for the rapid responses of pigs to the changes in their requirements.

## 5.5 ALLOCATION RULES AND RECOVERY

The last part of the thesis (Chapter IV) dealt with an extended test of the diet selection theory, the choice feeding of pigs that were diverted from their inherited path of growth, by being given access to an imbalanced feed (in terms of its protein:energy ratio). It was held that these pigs would resume their potential protein growth and restore their desired fatness. Such a prediction presumed the ability to predict what was the effect of limitation on the body composition of the animal and, by extension, what are the rules that the animal allocates the scarce resources between its functions.

Although Chapter IV did not deal with allocation rules (or dealt with them only briefly) it was felt that such a knowledge was quite important. The lack of knowledge on both allocation rules and recovery growth has led to the suggestion of a theory which was contradicted by the results of Experiment 5. Pigs that had undergone a period of limitation, which resulted in slower protein gain and increased fatness, selected a diet that enabled them to undergo true compensatory growth (in the sense of protein growth other than the feed processing organs' compensatory protein growth). However, it was likely that the observed compensation was not complete and was dependant on the length of the restriction.

The problems of predicting lipid and protein gains following a period of restricted feeding or feeding on limiting feeds are of practical importance, since they might influence the choice of feeding programmes for pigs. If a loss of time in one period

can be completely regained in a subsequent period, it is not necessary always to avoid under-feeding in order to attain maximum performance. If on the other hand, such a loss of time can not be regained, it is important to feed pigs so that they attain their potential at all times, especially when the potential is to be observed. Where pigs are fed on a single feed for a long period of time (eg. on a grower feed from 10-40 kg liveweight) it is possible for the protein content of this feed to change from being inadequate, to balanced, to abundant, during the course of the feeding period. Growth on such a feed in the later part of the period may reflect, in part, 'compensation' for growth previously foregone. Similar compensation can be observed when the pig is restricted for a period, as a result of poor management (eg. competition at the trough, not truly *ad libitum* feeding) and then is given free and continuous access to a high quality feed. Such a compensatory effect could have an important effect on the shape of the growth curve and might be misinterpreted and influence decisions in commercial practice.

## 5.6 DEVELOPING A THEORY

The need for nutritional theory is now widely recognised (France and Thornley, 1984; Emmans and Fisher, 1986). Agricultural research has reached a stage where quantitative methods of experimentation and of thought are increasingly taking over. Nutritional science is now mature enough for methods of combining the results of experiments of different kinds and for considering the effects of many interacting factors which influence the outcome of nutritional experiment. Thus research has not to be repeated endlessly as circumstances change, but the different components of a system can be considered explicitly.

The nutritional theory described in this thesis has focussed on the question: how am I going to feed an animal in order for it to growth as fast as it can? The theory was expanded by the use of two feeds, which differed in one or more nutritional

variable, given as a choice to the pigs. Two points have been stressed specifically in this thesis: the first was that the theory used here described events for a particular animal in a state at a time. Thus the importance of the individual was given particular emphasis. The second was that the importance of describing sufficiently a feeding experiment; not only by describing the animals involved, but also the feeds (possibly in dimensions that are not very significant in single feeding) and the environment used. Many aspects of this nutritional theory merit further investigation and other aspects have not been dealt with specifically here (eg. allocation rules and growth recovery). However, since a theory is an evolving thing 'it is vital that theories are proposed, tested, criticised and replaced' (Emmans and Fisher, 1986).

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## APPENDIX I

### The Feed Intake Model

```
C
C CONSTANTS DCP,V,HL,WL,HP,WP,EP
C INPUTS  W,FCPC,DEC,T,B,MPMAS,C,LPRM
C OUTPUT  H,MEM,CPM,FMEC,FPC,FI,PR,LR,P,PRM,ER,LRDES,MERQ,HLST
C
C
C
C
C
C
C
C
C
C
C
C
C
      INTEGER KEY
      REAL DCP,V,HL,WL,HP,WP,EP,W,FCPC,DEC,T,B,MPMAS,C,LPRM,H,
     *MEM,CPM,FMEC,FPC,FI,PR,LR,P,PRM,ER,LRDES,MERQ,HLST
      CALL ASSIGN(5,'TT:',3)
      CALL ASSIGN(7,'TT:',3)
C
C
      WRITE(7,700)
      READ(5,*)KEY
      IF(KEY.EQ.2)GOTO 500
C SET CONSTANTS
C
C
      DCP=0.9
      V=0.8
      HL=39.6
      WL=14.9
      HP=23.7
      WP=20.2
      EP=0.85
C
C
C ASKS FOR INPUTS
      WRITE(7,705)
      READ(5,*)W
      WRITE(7,710)
      READ(5,*)FCPC
      WRITE(7,715)
      READ(5,*)DEC
      WRITE(7,720)
      READ(5,*)T
      WRITE(7,722)
      READ(5,*)B
      WRITE(7,723)
      READ(5,*)MPMAS
      WRITE(7,724)
      READ(5,*)C
```

```
      WRITE(7,725)
      READ(5,*)LPRM
C
C GOES ONTO OUTPUT CALCS
C
      H=(0.25+0.06*(38-T))*(W**0.67)
      MEM=0.719*(W**0.63)
      CPM=0.0009375*(W**0.75)
      FMEC=DEC*(0.997-0.189*FCPC)
      FPC=DCP*V*FCPC
      FI=H*(HL+WL)-HL*MEM+CPM*(HL*WP*EP-WL*HP*EP)
      FI=FI/(WL*FMEC+FPC*(HL*WP*EP-WL*HP*EP))
      PR=EP*(FI*FPC-CPM)
      LR=(FI*FMEC-HP*PR-H)/HL
      P=W*0.16
      PRM=B*P*(ALOG(MPMAS/P))
      ER=(HL*LR)+(HP*PR)
      LRDES=PRM*(LPRM*C)*((P/MPMAS)**(C-1))
      IF(PR.LT.PRM)GOTO 150
      PR=PRM
      FI=(CPM+(PR/EP))/(FCPC*DCP*V)
      LR=((FI*FMEC)-(HP*PR)-H)/HL
      ER=(HL*LR)+(HP*PRM)
      IF(LR.GT.LRDES)GOTO 150
      LR=LRDES
      ER=(HL*LRDES)+(HP*PRM)
      MERQ=MEM+(HL+WL)*LRDES+(HP+WP)*PRM
      FI=(MERQ)/FMEC
      HLST=(FI*FMEC)-((HP*PRM)+(HL*LRDES))
      IF(HLST.LE.H)GOTO 100
      LR=(H-MEM-(WP*PRM))/WL
      ER=(HL*LR)+(HP*PRM)
      FI=(H+ER)/FMEC
      GOTO 150
  100 FI=(H+ER)/FMEC
C
C LISTS INPUTS AND OUTPUTS
  150 WRITE(7,730)W,FCPC,DEC,T,B,MPMAS,C,LPRM
C
      WRITE(7,735)H,MEM,CPM,FMEC,FPC,FI,PR,LR,P,PRM,ER,LRDES,
     *MERQ,HLST
C
C
  500 STOP
  700 FORMAT(1H,'THIS PROG CALCS SOME PIG NUMBERS ',
     */'  DO YOU WANT TO RUN IT -   TO CONTINUE   TYPE IN    1',
     */'                          TO STOP       TYPE IN     2')
  705 FORMAT(1H,' TYPE IN W ')
  710 FORMAT(1H,' TYPE IN FCPC ')
  715 FORMAT(1H,' TYPE IN  DEC ')
  720 FORMAT(1H,' TYPE IN    T ')
  722 FORMAT(1H,' TYPE IN    B ')
  723 FORMAT(1H,' TYPE IN MPMAS ')
  724 FORMAT(1H,' TYPE IN    C ')
  725 FORMAT(1H,' TYPE IN LPRM ')
  730 FORMAT(1H,' INPUT VALUES W',F7.3,' FCPC',F7.3,' DEC',F7.3,' T',
     *F7.3,' B'F7.3,' MPMAS'F7.3,' C'F7.3,' LPRM'F7.3)
  735 FORMAT(1H,' OUTPUT VALUES',
```

```
*/' H     =',F7.3,
*/' MEM   =',F7.3,
*/' CPM   =',F7.3,
*/' FMEC  =',F7.3,
*/' FPC   =',F7.3,
*/' FI    =',F7.3,
*/' PR    =',F7.3,
*/' LR    =',F7.3,
*/' P     =',F7.3,
*/' PRM   =',F7.3,
*/' ER    =',F7.3,
*/' LRDES   =',F7.3,
*/' MERQ  =',F7.3,
*/' HLST  =',F7.3)
 END
```

## APPENDIX Ia

The equations used to predict the rate of feed intake (FI) are:

| | | |
|---|---|---|
| Energy supplied by the feed | $FI.FMEC = ER + HL$ | (30) |
| Energy retained in the body | $ER = h_p.PR + h_l.LR$ | (31) |
| Heat produced by the body functions | $HP = ME_m + w_p.PR + w_l.LR$ | (34) |
| In a thermally neutral environment | $HP = HL = H$ | (35) |
| Protein supplied by the feed | $FI.FPC = CP_m + 1/e_p.PR$ | (37) |

By substituting (31) into (30) and (35) into (34) we get:

$$FI.FMEC = h_p.PR + h_l.LR + H \tag{41}$$

$$H = ME_m + w_p.PR + w_l.LR \tag{42}$$

$$FI.FPC = CP_m + 1/e_p.PR \tag{37}$$

Equations (41), (42) and (37) contain three unknowns (namely, FI, PR and LR) and therefore they can be solved for any of the unknowns (in this case for FI).

From (41) and (42):

$$FI.FMEC = h_p.PR - (h_l/w_l).(H - ME_m - w_p.PR) + H \tag{43}$$

Hence:

$$FI.FMEC = h_p.PR - (h_l/w_l)\, w_p.PR + (h_l/w_l).H - (h_l/w_l).\, ME_m + H \tag{43a}$$

Hence:

$$FI.FMEC = PR.(h_p - (h_l/w_l).w_p) + (h_l/w_l).H - (h_l/w_l).ME_m + H \tag{43b}$$

Substituting for PR from (37):

$$FI.FMEC = (FI.FPC - CP_m).e_p.(h_p-(h_l/w_l).w_p) + (h_l/w_l).H - (h_l/w_l).ME_m + H \tag{44}$$

Hence:

$$FI.FMEC = FI.FPC.(h_p-(h_l/w_l).w_p).e_p - CP_m.e_p.(h_p -(h_l/w_l).w_p) + (h_l/w_l).H -(h_l/w_l).ME_m + H \tag{44a}$$

Hence:

$$FI.(FMEC - FPC.\, (h_p -(h_l/w_l).e_p) = -CP_m.e_p.(h_p -(h_l/w_l).w_p) + (h_l/w_l).\, H -(h_l/w_l).ME_m + H \tag{44b}$$

Hence:

$$FI = \frac{-CP_m.e_p.(h_p-(h_l/w_l).w_p) + (h_l/w_l).H -(h_l/w_l).ME_m + H}{(FMEC - FPC.(h_p -(h_l/w_l).w_p).e_p)} \tag{44c}$$

Hence:

$$FI = \frac{-CP_m.e_p.(h_p.w_l - h_l.w_p) + h_l.H - h_l.ME_m + w_l.H}{(FMEC.w_l - FPC.(h_p.w_l - h_l.w_p)e_p)} \quad (44d)$$

Hence:

$$FI = \frac{H.(h_l + w_l) - h_l.ME_m + CP_m.(h_l.w_p.e_p - w_l.h_p.e_p)}{w_l.FMEC + FPC\ (h_l.w_p.e_p - w_l.h_p.e_p)} \quad (44e)$$

Equation (44e) is the equation incorporated into the FORTRAN model.

## APPENDIX II

### A. Liveweight and Feed Intake data - Experiment 1.

1-40 = Pig Identity; M or F = Sex; LWT = Liveweight (g); FI = Feed Intake (g); L, M or H = Feed

| ROW | 24M LWT | 24FI L | 24FI M | 40M LWT | 40FI L | 40FI M | 29F LWT | 29FI L | 29FI M |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12960 | 313 | 380 | 12750 | 614 | 88 | 11860 | 112 | 257 |
| 2 | 13090 | 3 | 698 | 13320 | 734 | 35 | 11920 | 7 | 573 |
| 3 | 13720 | 8 | 632 | 13620 | 793 | 17 | 12770 | 9 | 495 |
| 4 | 14110 | 6 | 696 | 13830 | 652 | 42 | 13020 | 11 | 542 |
| 5 | 15010 | 4 | 678 | 13450 | 850 | 8 | 13400 | 4 | 320 |
| 6 | 15340 | 1 | 665 | 14910 | 792 | 23 | 13500 | 82 | 531 |
| 7 | 16060 | 4 | 779 | 15280 | 775 | 18 | 14240 | 55 | 505 |
| 8 | 17110 | 7 | 818 | 15640 | 630 | 9 | 14670 | 124 | 453 |
| 9 | 17520 | 4 | 918 | 16190 | 653 | 3 | 15470 | 73 | 602 |
| 10 | 18580 | 11 | 748 | 16470 | 666 | 4 | 15930 | 37 | 541 |
| 11 | 19310 | 3 | 867 | 17150 | 743 | 24 | 16270 | 261 | 730 |
| 12 | 19740 | 548 | 206 | 17560 | 874 | 3 | 17580 | 212 | 597 |
| 13 | 20100 | 564 | 217 | 17740 | 680 | 2 | 17990 | 119 | 658 |
| 14 | 20950 | 767 | 8 | 18090 | 937 | 9 | 18910 | 655 | 307 |
| 15 | 21810 | 1097 | 9 | 18850 | 967 | 1 | 19270 | 204 | 484 |
| 16 | 21860 | 1183 | 15 | 19140 | 886 | 2 | 19920 | 275 | 662 |
| 17 | 21970 | 1129 | 0 | 19530 | 997 | 0 | 20460 | 134 | 543 |
| 18 | 22560 | 1095 | 1 | 20200 | 963 | 270 | 21130 | 244 | 375 |
| 19 | 22960 | 999 | 35 | 20960 | 991 | 1 | 21630 | 353 | 546 |
| 20 | 23440 | 1020 | 5 | 21630 | 976 | 3 | 21960 | 178 | 700 |
| 21 | 23570 | 1045 | 108 | 22180 | 1007 | 2 | 22660 | 535 | 632 |
| 22 | 24150 | 1145 | 23 | 22640 | 1254 | 2 | 23840 | 197 | 667 |
| 23 | 24670 | 174 | 1169 | 22890 | 1228 | 9 | 24060 | 348 | 482 |
| 24 | 25400 | 3 | 1260 | 23600 | 1195 | 0 | 24760 | 153 | 817 |
| 25 | 26650 | 2 | 1321 | 24900 | 405 | 1207 | 25540 | 436 | 765 |
| 26 | 27680 | 2 | 1371 | 26320 | 881 | 345 | 26430 | 566 | 527 |
| 27 | 29000 | 0 | 1351 | 26740 | 1219 | 32 | 26900 | 681 | 586 |
| 28 | 29630 | | | 27130 | 1469 | 106 | 27270 | 696 | 600 |
| 29 | | | | 27760 | 1398 | 4 | 28180 | 539 | 729 |
| 30 | | | | 28950 | 1515 | 12 | 28930 | 734 | 629 |
| 31 | | | | 29690 | 1616 | 0 | 30020 | | |
| 32 | | | | 30130 | | | | | |

| ROW | 23F LWT | 23FI L | 23FI M | 21F LWT | 21FI L | 21FI M | 34F LWT | 34FI L | 34FI M |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11860 | 617 | 12 | 12180 | 278 | 274 | 12080 | 374 | 270 |
| 2 | 12180 | 586 | 14 | 12370 | 19 | 548 | 12540 | 496 | 101 |
| 3 | 12190 | 243 | 7 | 13310 | 32 | 673 | 12690 | 700 | 2 |
| 4 | 12280 | 307 | 4 | 13940 | 14 | 745 | 12750 | 512 | 16 |
| 5 | 12260 | 692 | 27 | 14670 | 72 | 517 | 13330 | 806 | 47 |
| 6 | 12500 | 763 | 11 | 14590 | 116 | 714 | 13750 | 793 | 1 |
| 7 | 13280 | 884 | 4 | 15480 | 85 | 602 | 14340 | 999 | 13 |
| 8 | 13960 | 995 | 5 | 16010 | 147 | 712 | 14920 | 1170 | 6 |
| 9 | 14260 | 1275 | 26 | 16620 | 363 | 609 | 15620 | 1062 | 4 |
| 10 | 15610 | 1244 | 6 | 17340 | 271 | 541 | 16110 | 931 | 0 |
| 11 | 16050 | 1247 | 12 | 18150 | 284 | 618 | 16270 | 956 | 0 |
| 12 | 17040 | 958 | 0 | 18460 | 287 | 717 | 16840 | 925 | 104 |
| 13 | 17390 | 1036 | 21 | 19000 | 254 | 866 | 17030 | 1101 | 75 |
| 14 | 17710 | 1180 | 6 | 19740 | 239 | 884 | 17790 | 1110 | 0 |
| 15 | 18300 | 1375 | 0 | 20780 | 159 | 976 | 18260 | 1025 | 0 |
| 16 | 18630 | 1082 | 0 | 21000 | 359 | 508 | 18820 | 1239 | 3 |
| 17 | 19420 | 1133 | 0 | 21600 | 447 | 685 | 19800 | 1422 | 63 |
| 18 | 19910 | 1346 | 9 | 22110 | 419 | 679 | 20670 | 1084 | 127 |
| 19 | 20470 | 1468 | 79 | 22930 | 316 | 802 | 20960 | 1189 | 115 |
| 20 | 21720 | 1501 | 0 | 23990 | 713 | 456 | 21910 | 1284 | 280 |
| 21 | 22650 | 1570 | 3 | 24440 | 854 | 332 | 22740 | 663 | 650 |
| 22 | 23240 | 1619 | 0 | 25460 | 696 | 509 | 23540 | 697 | 729 |
| 23 | 23740 | 1073 | 633 | 26420 | 748 | 584 | 23850 | 767 | 554 |
| 24 | 25280 | 1162 | 254 | 27030 | 716 | 439 | 24950 | 1105 | 364 |
| 25 | 25670 | 1482 | 552 | 27940 | 730 | 208 | 25880 | 1255 | 28 |
| 26 | 26040 | 1600 | 180 | 27210 | 842 | 247 | 26430 | 670 | 480 |
| 27 | 27710 | 1618 | 191 | 28510 | 577 | 403 | 26860 | 1060 | 464 |
| 28 | 28630 | 1561 | 29 | 28830 | 797 | 401 | 27290 | 820 | 650 |
| 29 | 29400 | 1663 | 34 | 29110 | 640 | 438 | 28960 | 932 | 527 |
| 30 | 30090 | | | 29680 | 663 | 477 | 29020 | 908 | 350 |
| 31 | | | | 30510 | | | 29900 | 1124 | 361 |
| 32 | | | | | | | 30630 | | |

| ION | 38M LWT | 38FI L | 38FI H | 35M LWT | 35FI L | 35FI H | 31F LWT | 31FI L | 31FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12480 | 542 | 23 | 12150 | 488 | 30 | 11830 | 634 | 140 |
| 2 | 12570 | 496 | 72 | 11480 | 514 | 8 | 12230 | 445 | 181 |
| 3 | 12960 | 742 | 33 | 12510 | 110 | 11 | 12670 | 640 | 140 |
| 4 | 13340 | 608 | 58 | 12720 | 575 | 30 | 13090 | 668 | 243 |
| 5 | 13740 | 664 | 44 | 13140 | 623 | 6 | 13810 | 663 | 250 |
| 6 | 13770 | 869 | 12 | 13460 | 622 | 144 | 14870 | 711 | 315 |
| 7 | 14300 | 758 | 55 | 13890 | 843 | 48 | 15570 | 597 | 242 |
| 8 | 14750 | 898 | 58 | 14700 | 765 | 23 | 15890 | 817 | 117 |
| 9 | 15470 | 957 | 83 | 15100 | 457 | 101 | 16510 | 875 | 112 |
| 10 | 16050 | 926 | 76 | 14940 | 700 | 262 | 17170 | 854 | 155 |
| 11 | 16540 | 775 | 163 | 15840 | 511 | 356 | 17550 | 981 | 150 |
| 12 | 16960 | 798 | 175 | 16460 | 717 | 167 | 18430 | 1121 | 133 |
| 13 | 17540 | 824 | 102 | 17280 | 598 | 327 | 19180 | 1002 | 83 |
| 14 | 18050 | 934 | 72 | 18180 | 626 | 406 | 19350 | 1091 | 129 |
| 15 | 18590 | 677 | 253 | 18960 | 424 | 482 | 20250 | 1161 | 139 |
| 16 | 19250 | 942 | 114 | 20000 | 572 | 435 | 21240 | 1218 | 64 |
| 17 | 20010 | 850 | 95 | 20640 | 654 | 310 | 21840 | 1200 | 120 |
| 18 | 20180 | 871 | 75 | 21630 | 709 | 360 | 22660 | 1354 | 176 |
| 19 | 20570 | 1075 | 80 | 22060 | 833 | 365 | 23290 | 1007 | 137 |
| 20 | 21320 | 1046 | 325 | 22720 | 828 | 246 | 24090 | 934 | 208 |
| 21 | 22210 | 1036 | 76 | 23410 | 851 | 85 | 24780 | 1131 | 169 |
| 22 | 22780 | 1008 | 89 | 24430 | 981 | 234 | 25610 | 1118 | 161 |
| 23 | 22890 | 930 | 190 | 24770 | 959 | 79 | 26670 | 957 | 61 |
| 24 | 24110 | 1031 | 351 | 26010 | 973 | 309 | 26670 | 887 | 180 |
| 25 | 24990 | 1240 | 102 | 26560 | 1160 | 441 | 27160 | 1098 | 192 |
| 26 | 25820 | 1070 | 82 | 27520 | 1190 | 180 | 27880 | 1164 | 256 |
| 27 | 26420 | 1158 | 408 | 28840 | 1203 | 217 | 28680 | 887 | 229 |
| 28 | 26980 | 888 | 392 | 29280 | 1087 | 226 | 29510 | 928 | 281 |
| 29 | 28070 | 965 | 223 | 30100 | | | 30150 | | |
| 30 | 28560 | 833 | 165 | | | | | | |
| 31 | 29110 | 1021 | 185 | | | | | | |
| 32 | 29720 | 780 | 163 | | | | | | |
| 33 | 30210 | | | | | | | | |

| ROW | 27F LWT | 27FI L | 27FI H | 37F LWT | 37FI L | 37FI H | 30F LWT | 30FI L | 30FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12030 | 739 | 17 | 12340 | 792 | 371 | 12010 | 387 | 32 |
| 2 | 12270 | 710 | 11 | 12490 | 782 | 16 | 12370 | 805 | 4 |
| 3 | 12280 | 581 | 3 | 13070 | 638 | 13 | 13210 | 588 | 0 |
| 4 | 12720 | 645 | 19 | 13490 | 823 | 4 | 13500 | 31 | 2 |
| 5 | 12540 | 702 | 51 | 13730 | 789 | 11 | 13670 | 175 | 15 |
| 6 | 12680 | 734 | 11 | 14160 | 651 | 100 | 13790 | 352 | 6 |
| 7 | 13260 | 950 | 16 | 14480 | 686 | 34 | 13870 | 655 | 4 |
| 8 | 14020 | 916 | 63 | 14650 | 910 | 62 | 14510 | 879 | 2 |
| 9 | 14490 | 882 | 149 | 15450 | 1004 | 7 | 14950 | 945 | 4 |
| 10 | 15370 | 958 | 15 | 16190 | 1008 | 31 | 15550 | 1030 | 7 |
| 11 | 15920 | 779 | 270 | 16600 | 927 | 207 | 16230 | 983 | 11 |
| 12 | 16620 | 760 | 296 | 17310 | 955 | 178 | 16740 | 1014 | 4 |
| 13 | 17380 | 895 | 139 | 17710 | 1059 | 169 | 16980 | 969 | 11 |
| 14 | 18290 | 798 | 224 | 18410 | 1124 | 229 | 17680 | 959 | 26 |
| 15 | 18990 | 679 | 231 | 19230 | 1244 | 159 | 18080 | 1104 | 27 |
| 16 | 19280 | 616 | 393 | 20230 | 1323 | 80 | 18860 | 1200 | 40 |
| 17 | 20270 | 848 | 173 | 20910 | 1221 | 90 | 19290 | 1117 | 30 |
| 18 | 20750 | 811 | 341 | 21190 | 1264 | 14 | 20030 | 1215 | 39 |
| 19 | 21680 | 841 | 460 | 21990 | 1325 | 71 | 20630 | 1132 | 49 |
| 20 | 22270 | 647 | 329 | 22530 | 1391 | 49 | 21570 | 940 | 124 |
| 21 | 22880 | 875 | 333 | 23650 | 1160 | 173 | 22170 | 1052 | 120 |
| 22 | 23770 | 790 | 327 | 24580 | 1106 | 11 | 22270 | 860 | 162 |
| 23 | 24390 | 909 | 430 | 24570 | 1195 | 6 | 22970 | 1011 | 278 |
| 24 | 24800 | 992 | 199 | 25320 | 1370 | 49 | 23650 | 738 | 379 |
| 25 | 25820 | 893 | 321 | 26040 | 1450 | 227 | 24380 | 1042 | 289 |
| 26 | 26730 | 1085 | 320 | 26840 | 1531 | 52 | 25650 | 810 | 219 |
| 27 | 27780 | 979 | 230 | 27750 | 1333 | 3 | 26380 | 740 | 246 |
| 28 | 28600 | 1149 | 360 | 28460 | 1300 | 3 | 26710 | 900 | 231 |
| 29 | 29310 | 1148 | 320 | 28930 | 1587 | 235 | 27620 | 897 | 184 |
| 30 | 30260 | | | 29510 | 1617 | 13 | 28060 | 988 | 227 |
| 31 | | | | 30690 | | | 29390 | 981 | 198 |
| 32 | | | | | | | 29510 | 816 | 196 |
| 33 | | | | | | | 30640 | | |

| ROW | 36M LWT | 36FI M | 36FI H | 28M LWT | 28FI M | 28FI H | 22F LWT | 22FI M | 22FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12700 | 489 | 124 | 11970 | 656 | 13 | 12120 | 191 | 378 |
| 2 | 13240 | 671 | 8 | 12660 | 652 | 21 | 12540 | 480 | 165 |
| 3 | 13360 | 784 | 3 | 13100 | 635 | 8 | 13070 | 30 | 0 |
| 4 | 14320 | 901 | 3 | 13590 | 585 | 2 | 13870 | 780 | 22 |
| 5 | 15240 | 970 | 1 | 14100 | 495 | 4 | 14450 | 715 | 2 |
| 6 | 16010 | 963 | 0 | 14400 | 667 | 5 | 14890 | 876 | 12 |
| 7 | 16540 | 888 | 0 | 15290 | 724 | 5 | 15470 | 750 | 4 |
| 8 | 17400 | 1058 | 0 | 16080 | 643 | 4 | 16150 | 792 | 11 |
| 9 | 18130 | 1205 | 0 | 16540 | 669 | 5 | 16810 | 952 | 0 |
| 10 | 19200 | 1074 | 0 | 17360 | 833 | 5 | 17530 | 1019 | 1 |
| 11 | 19800 | 787 | 0 | 17970 | 767 | 5 | 18260 | 853 | 6 |
| 12 | 19840 | 823 | 7 | 18630 | 790 | 2 | 18880 | 970 | 2 |
| 13 | 20050 | 1015 | 1 | 19260 | 964 | 1 | 19730 | 1114 | 2 |
| 14 | 21620 | 1045 | 1 | 19890 | 796 | 3 | 20410 | 972 | 0 |
| 15 | 22470 | 960 | 3 | 20630 | 761 | 3 | 21110 | 1004 | 1 |
| 16 | 22570 | 1160 | 4 | 21140 | 927 | 3 | 21810 | 996 | 4 |
| 17 | 23390 | 1200 | 0 | 21710 | 1018 | 0 | 22400 | 835 | 6 |
| 18 | 23970 | 1217 | 8 | 22620 | 872 | 6 | 22950 | 815 | 4 |
| 19 | 24550 | 1134 | 2 | 23170 | 1099 | 3 | 23390 | 832 | 4 |
| 20 | 25770 | 952 | 5 | 24130 | 974 | 304 | 24080 | 7 | 808 |
| 21 | 26380 | 1241 | 3 | 24990 | 862 | 250 | 25030 | 57 | 694 |
| 22 | 27000 | 1370 | 0 | 25860 | 1040 | 120 | 25700 | 745 | 229 |
| 23 | 27820 | 1478 | 0 | 25910 | 960 | 70 | 26320 | 1069 | 38 |
| 24 | 29110 | 1492 | 1 | 26950 | 877 | 80 | 27090 | 1142 | 2 |
| 25 | 30630 | | | 27180 | 997 | 3 | 27850 | 1209 | 1 |
| 26 | | | | 28140 | 1136 | 4 | 28590 | 1213 | 3 |
| 27 | | | | 29060 | 1190 | 4 | 29310 | 1304 | 2 |
| 28 | | | | 30070 | | | 30480 | | |

| ROW | 25F LWT | 25FI M | 25FI H | 32F LWT | 32FI M | 32FI H | 39F LWT | 39FI M | 39FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12460 | 428 | 24 | 11870 | 615 | 30 | 11910 | 570 | 19 |
| 2 | 12580 | 517 | 7 | 12310 | 561 | 19 | 12730 | 556 | 6 |
| 3 | 13310 | 601 | 8 | 12880 | 677 | 14 | 13260 | 577 | 2 |
| 4 | 14010 | 683 | 9 | 13420 | 674 | 12 | 13730 | 476 | 6 |
| 5 | 14640 | 835 | 9 | 14200 | 647 | 5 | 14000 | 560 | 5 |
| 6 | 15140 | 836 | 4 | 14800 | 812 | 13 | 14470 | 606 | 2 |
| 7 | 16000 | 779 | 5 | 15260 | 845 | 10 | 15160 | 592 | 1 |
| 8 | 16680 | 827 | 23 | 15900 | 773 | 14 | 15500 | 621 | 1 |
| 9 | 17280 | 998 | 12 | 16580 | 756 | 9 | 15800 | 630 | 1 |
| 10 | 17840 | 891 | 15 | 17310 | 869 | 5 | 16420 | 621 | 2 |
| 11 | 18760 | 903 | 8 | 18120 | 833 | 7 | 16650 | 484 | 2 |
| 12 | 18930 | 1060 | 3 | 18670 | 710 | 5 | 16580 | 629 | 1 |
| 13 | 20150 | 855 | 7 | 19160 | 1044 | 16 | 16910 | 604 | 4 |
| 14 | 21020 | 1032 | 7 | 19720 | 879 | 28 | 17300 | 507 | 1 |
| 15 | 21540 | 1192 | 3 | 20370 | 869 | 12 | 17630 | 501 | 1 |
| 16 | 22500 | 1123 | 4 | 21350 | 1009 | 46 | 17420 | 329 | 2 |
| 17 | 23290 | 1182 | 2 | 22160 | 866 | 12 | 17220 | 32 | 1 |
| 18 | 24260 | 990 | 3 | 23180 | 1080 | 30 | 16490 | 378 | 166 |
| 19 | 24480 | 1064 | 1 | 23760 | 666 | 409 | 17800 | 1088 | 57 |
| 20 | 25610 | 1265 | 8 | 24650 | 1043 | 33 | 19630 | 1020 | 108 |
| 21 | 26460 | 1329 | 4 | 25960 | 1117 | 4 | 20380 | 1046 | 142 |
| 22 | 27270 | 1275 | 5 | 26400 | 1100 | 14 | 21010 | 975 | 2 |
| 23 | 28110 | 1222 | 2 | 26770 | 1237 | 0 | 22070 | 1194 | 85 |
| 24 | 28650 | 1331 | 2 | 27850 | 1297 | 4 | 22270 | 1039 | 4 |
| 25 | 30220 | | | 28830 | 1414 | 0 | 23410 | 1232 | 190 |
| 26 | | | | 29470 | 1354 | 2 | 24580 | 935 | 302 |
| 27 | | | | 31320 | | | 25600 | 1126 | 55 |
| 28 | | | | | | | 26290 | 880 | 15 |
| 29 | | | | | | | 26550 | 1205 | 121 |
| 30 | | | | | | | 27990 | 1283 | 166 |
| 31 | | | | | | | 28590 | 1387 | 159 |
| 32 | | | | | | | 29790 | 1182 | 3 |
| 33 | | | | | | | 30720 | | |

| OW | 4M LWT | 4 FI L | 9M LWT | 9FI L | 3F LWT | 3FI L | 19F LWT | 19FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 11950 | 656 | 12300 | 559 | 12340 | 548 | 12050 | 480 |
| 2 | 12630 | 672 | 12530 | 419 | 12730 | 703 | 12550 | 601 |
| 3 | 12310 | 813 | 12580 | 797 | 13010 | 679 | 13120 | 791 |
| 4 | 12450 | 740 | 13200 | 709 | 13340 | 708 | 13610 | 767 |
| 5 | 13330 | 876 | 13480 | 810 | 13800 | 792 | 13720 | 851 |
| 6 | 13490 | 1001 | 14040 | 788 | 14010 | 845 | 14260 | 825 |
| 7 | 14350 | 982 | 14240 | 930 | 14730 | 950 | 14810 | 847 |
| 8 | 14760 | 968 | 14820 | 1031 | 15000 | 983 | 15120 | 974 |
| 9 | 15650 | 887 | 15010 | 1028 | 15580 | 858 | 15520 | 1032 |
| 10 | 15770 | 1116 | 15320 | 1146 | 16040 | 1094 | 16320 | 995 |
| 11 | 16370 | 864 | 16020 | 1235 | 16370 | 1077 | 16890 | 1058 |
| 12 | 16670 | 1159 | 16850 | 1320 | 16640 | 1230 | 17710 | 1165 |
| 13 | 17690 | 999 | 17500 | 1288 | 17810 | 1063 | 18250 | 1133 |
| 14 | 18030 | 1165 | 18420 | 1327 | 17970 | 1238 | 18720 | 961 |
| 15 | 18900 | 882 | 18640 | 1338 | 18730 | 1259 | 18620 | 928 |
| 16 | 18970 | 1106 | 19090 | 1426 | 19460 | 1227 | 19290 | 895 |
| 17 | 19510 | 1170 | 19990 | 1348 | 19880 | 1249 | 20010 | 1008 |
| 18 | 19810 | 1194 | 20490 | 1403 | 20740 | 1072 | 20540 | 1127 |
| 19 | 20870 | 1363 | 20870 | 1500 | 21160 | 1265 | 21190 | 1269 |
| 20 | 21540 | 1402 | 21790 | 1414 | 21440 | 1237 | 21470 | 1160 |
| 21 | 22440 | 1410 | 22550 | 1443 | 22350 | 1341 | 22400 | 1188 |
| 22 | 23520 | 1369 | 23260 | 1480 | 22930 | 1371 | 22970 | 1292 |
| 23 | 23940 | 1451 | 23610 | 1400 | 23780 | 1356 | 23310 | 1276 |
| 24 | 24300 | 1249 | 24650 | 1500 | 24400 | 1404 | 24200 | 885 |
| 25 | 24450 | 1424 | 25080 | 1434 | 24910 | 1157 | 24220 | 1104 |
| 26 | 25270 | 1520 | 26450 | 1428 | 25500 | 1442 | 24790 | 1275 |
| 27 | 26380 | 1598 | 26480 | 1470 | 26090 | 1492 | 25300 | 1080 |
| 28 | 26650 | 1522 | 27430 | 1484 | 27060 | 1660 | 26510 | 1412 |
| 29 | 27840 | 1710 | 27690 | 1457 | 27930 | 1651 | 26790 | 1448 |
| 30 | 29820 | 1311 | 28490 | 1519 | 28550 | 1283 | 27770 | 1386 |
| 31 | 29470 | 1593 | 29550 | 1529 | 29080 | 1408 | 28560 | 1353 |
| 32 | 29980 | 1589 | 30390 | | 29570 | 1759 | 28970 | 1424 |
| 33 | 30950 | | | | 30830 | | 29830 | |

| ROW | 20F LWT | 20FI L | 12F LWT | 12FI L | 8M LWT | 8FI M | 7M LWT | 7FI M |
|---|---|---|---|---|---|---|---|---|
| 1 | 12560 | 406 | 11850 | 523 | 11970 | 424 | 12400 | 626 |
| 2 | 12060 | 724 | 12200 | 601 | 12260 | 468 | 12660 | 559 |
| 3 | 13120 | 781 | 12520 | 542 | 12690 | 512 | 13010 | 606 |
| 4 | 13590 | 648 | 12690 | 656 | 13120 | 518 | 13480 | 549 |
| 5 | 13690 | 868 | 13270 | 702 | 13560 | 534 | 14130 | 734 |
| 6 | 14230 | 952 | 13330 | 410 | 13900 | 414 | 14450 | 327 |
| 7 | 14580 | 979 | 13280 | 667 | 13900 | 537 | 14780 | 10 |
| 8 | 15350 | 975 | 13820 | 578 | 14490 | 533 | 14300 | 358 |
| 9 | 15830 | 865 | 14080 | 775 | 15210 | 632 | 14770 | 541 |
| 10 | 15940 | 972 | 14610 | 721 | 15510 | 458 | 14830 | 790 |
| 11 | 16550 | 1045 | 15360 | 924 | 15990 | 561 | 16070 | 1047 |
| 12 | 17310 | 1108 | 15660 | 788 | 16290 | 561 | 17260 | 1020 |
| 13 | 17750 | 924 | 15970 | 654 | 16630 | 540 | 17780 | 1030 |
| 14 | 18270 | 1113 | 16150 | 810 | 16910 | 622 | 18140 | 1032 |
| 15 | 18740 | 982 | 16810 | 710 | 17620 | 710 | 18990 | 1150 |
| 16 | 19000 | 985 | 16940 | 776 | 18310 | 794 | 19760 | 1400 |
| 17 | 19860 | 1122 | 17190 | 843 | 19130 | 828 | 19880 | 1399 |
| 18 | 20270 | 1028 | 17690 | 862 | 19780 | 817 | 21580 | 1051 |
| 19 | 20660 | 947 | 18070 | 923 | 20410 | 770 | 22020 | 1089 |
| 20 | 21060 | 1009 | 18640 | 987 | 21030 | 855 | 23000 | 1100 |
| 21 | 21660 | 1043 | 19170 | 1071 | 21610 | 1037 | 24090 | 1264 |
| 22 | 22380 | 1062 | 19920 | 1115 | 22860 | 754 | 24790 | 862 |
| 23 | 22670 | 988 | 20360 | 1034 | 23270 | 1076 | 25630 | 1108 |
| 24 | 22920 | 1077 | 20800 | 1065 | 24530 | 945 | 26410 | 1260 |
| 25 | 23540 | 1109 | 21260 | 1117 | 24940 | 1035 | 27000 | 1244 |
| 26 | 24320 | 1323 | 22160 | 1220 | 25720 | 1019 | 27770 | 1182 |
| 27 | 24590 | 1318 | 22740 | 952 | 26550 | 1028 | 28570 | 1055 |
| 28 | 25310 | 1260 | 22920 | 1269 | 27400 | 975 | 29270 | 881 |
| 29 | 25540 | 1248 | 24020 | 1256 | 28430 | 691 | 29980 | 950 |
| 30 | 27130 | 1327 | 24360 | 1101 | 28760 | 743 | 30180 | |
| 31 | 27700 | 1280 | 24560 | 1056 | 29090 | 935 | | |
| 32 | 27520 | 1390 | 25080 | 1065 | 30000 | | | |
| 33 | 27900 | 1304 | 25920 | 1181 | | | | |
| 34 | 28930 | 1165 | 26060 | 1071 | | | | |
| 35 | 29150 | 1184 | 26640 | 952 | | | | |
| 36 | 29820 | 1194 | 27330 | 1155 | | | | |
| 37 | 30470 | | 27760 | 994 | | | | |
| 38 | | | 28100 | 1144 | | | | |
| 39 | | | 28630 | 1040 | | | | |
| 40 | | | 28930 | 1005 | | | | |
| 41 | | | 29730 | 1117 | | | | |
| 42 | | | 29840 | 1046 | | | | |
| 43 | | | 30020 | | | | | |

| ROW | 17M LWT | 17FI M | 6M LWT | 6FI M | 18F LWT | 18FI M | 11F LWT | 11FI M |
|---|---|---|---|---|---|---|---|---|
| 1 | 12100 | 717 | 11980 | 710 | 12250 | 413 | 12290 | 654 |
| 2 | 12810 | 706 | 12420 | 707 | 12450 | 705 | 12910 | 720 |
| 3 | 13410 | 761 | 13180 | 692 | 13580 | 807 | 13380 | 754 |
| 4 | 13990 | 663 | 13760 | 838 | 14240 | 559 | 14280 | 763 |
| 5 | 14500 | 710 | 14350 | 809 | 14640 | 667 | 15020 | 861 |
| 6 | 15050 | 721 | 15250 | 822 | 15310 | 594 | 15950 | 859 |
| 7 | 15860 | 832 | 15840 | 900 | 16130 | 737 | 16430 | 938 |
| 8 | 16560 | 869 | 16330 | 832 | 16740 | 817 | 17190 | 1015 |
| 10 | 17770 | 813 | 18230 | 623 | 18320 | 950 | 18970 | 998 |
| 11 | 18310 | 682 | 18400 | 795 | 18640 | 792 | 19810 | 887 |
| 12 | 19040 | 869 | 19030 | 939 | 19810 | 903 | 21040 | 991 |
| 13 | 19730 | 803 | 19800 | 1026 | 20790 | 811 | 21470 | 1039 |
| 14 | 20540 | 815 | 20470 | 1118 | 20980 | 999 | 22160 | 1078 |
| 15 | 21190 | 812 | 21300 | 1091 | 22170 | 1000 | 22800 | 1051 |
| 16 | 21990 | 748 | 22230 | 1072 | 22900 | 1075 | 24000 | 1033 |
| 17 | 22470 | 823 | 22870 | 994 | 24230 | 911 | 24540 | 1062 |
| 18 | 23210 | 950 | 23480 | 1077 | 24330 | 1012 | 25330 | 1133 |
| 19 | 23950 | 858 | 24450 | 1071 | 25430 | 897 | 25820 | 1115 |
| 20 | 24510 | 932 | 24810 | 1196 | 25880 | 872 | 26630 | 1041 |
| 21 | 25140 | 936 | 25670 | 1188 | 26500 | 1040 | 27250 | 1264 |
| 22 | 25750 | 932 | 26710 | 1298 | 27960 | 1135 | 28210 | 1302 |
| 23 | 26150 | 968 | 27110 | 1400 | 28550 | 1202 | 28820 | 1293 |
| 24 | 27200 | 1059 | 28100 | 1395 | 29360 | 1319 | 30300 | |
| 25 | 27700 | 1183 | 29140 | 1347 | 30140 | | | |
| 26 | 28810 | 1249 | 29930 | 1267 | | | | |
| 27 | 29530 | 1113 | | | | | | |
| 28 | 30530 | | | | | | | |

| ROW | 14F LWT | 14FI H | 16M LWT | 16FI H | 5M LWT | 5FI H | 15M LWT | 15FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 12220 | 581 | 12330 | 549 | 12610 | 647 | 12650 | 549 |
| 2 | 12870 | 614 | 12960 | 618 | 13240 | 450 | 13340 | 506 |
| 3 | 13700 | 695 | 13550 | 608 | 13610 | 460 | 13940 | 671 |
| 4 | 14290 | 698 | 14160 | 635 | 13740 | 490 | 14520 | 615 |
| 5 | 14570 | 809 | 14740 | 727 | 14520 | 698 | 14920 | 692 |
| 6 | 15430 | 823 | 15590 | 586 | 15590 | 601 | 15240 | 603 |
| 7 | 15990 | 890 | 16010 | 837 | 15690 | 728 | 16010 | 759 |
| 8 | 16810 | 997 | 16550 | 769 | 16370 | 650 | 16670 | 900 |
| 9 | 17560 | 835 | 17420 | 663 | 17030 | 824 | 17240 | 809 |
| 10 | 18310 | 811 | 18170 | 716 | 17940 | 500 | 18120 | 685 |
| 11 | 19250 | 940 | 19070 | 780 | 17990 | 1132 | 18160 | 689 |
| 12 | 19450 | 899 | 19200 | 652 | 19970 | 1000 | 18840 | 986 |
| 13 | 19950 | 892 | 19980 | 810 | 20340 | 695 | 19670 | 852 |
| 14 | 20410 | 814 | 21030 | 781 | 20960 | 987 | 20720 | 1006 |
| 15 | 21560 | 893 | 21360 | 916 | 21690 | 969 | 21260 | 1118 |
| 16 | 21800 | 1107 | 22430 | 956 | 22650 | 796 | 22290 | 1193 |
| 17 | 22490 | 892 | 22940 | 890 | 23050 | 790 | 23250 | 1086 |
| 18 | 23090 | 993 | 23740 | 702 | 23190 | 970 | 23880 | 949 |
| 19 | 24010 | 1111 | 24130 | 870 | 24110 | 1077 | 24730 | 922 |
| 20 | 24690 | 1133 | 24950 | 1074 | 24840 | 1013 | 25430 | 1132 |
| 21 | 25560 | 1264 | 25820 | 1224 | 25490 | 1058 | 26330 | 992 |
| 22 | 26020 | 1271 | 26690 | 1084 | 25930 | 962 | 26930 | 1102 |
| 23 | 27370 | 1429 | 27890 | 1112 | 27010 | 892 | 27370 | 970 |
| 24 | 27770 | 1346 | 28090 | 1218 | 27440 | 986 | 28510 | 1205 |
| 25 | 28810 | 1438 | 29110 | 1367 | 28090 | 1173 | 29300 | 1134 |
| 26 | 29600 | 1419 | 29920 | | 28990 | 1287 | 30070 | |
| 27 | 30550 | | | | 30130 | | | |

c

| ROW | 1F LWT | 1FI H | 10F LWT | 10FI H | 13F LWT | 13FI H | 2F LWT | 2FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 12000 | 727 | 12190 | 534 | 12070 | 481 | 11970 | 598 |
| 2 | 12270 | 632 | 12500 | 544 | 12490 | 596 | 12430 | 672 |
| 3 | 13190 | 758 | 13170 | 610 | 13560 | 482 | 12970 | 636 |
| 4 | 13950 | 776 | 13800 | 772 | 13890 | 559 | 13960 | 658 |
| 5 | 14520 | 784 | 14860 | 826 | 14680 | 548 | 14870 | 568 |
| 6 | 15100 | 789 | 15100 | 597 | 15190 | 607 | 15420 | 485 |
| 7 | 16100 | 720 | 15710 | 720 | 15720 | 656 | 15790 | 448 |
| 8 | 16320 | 742 | 16480 | 772 | 16380 | 530 | 16030 | 464 |
| 9 | 16940 | 918 | 17110 | 611 | 16920 | 662 | 16750 | 614 |
| 10 | 17890 | 913 | 17210 | 860 | 17330 | 642 | 17050 | 419 |
| 11 | 18640 | 774 | 17950 | 812 | 17780 | 658 | 17570 | 848 |
| 12 | 19240 | 933 | 18520 | 724 | 18770 | 659 | 18730 | 862 |
| 13 | 19780 | 995 | 18970 | 930 | 19090 | 867 | 19750 | 873 |
| 14 | 20440 | 1039 | 19430 | 1008 | 20170 | 818 | 19930 | 871 |
| 15 | 21310 | 1150 | 20790 | 1127 | 20280 | 887 | 21010 | 990 |
| 16 | 22020 | 943 | 21290 | 888 | 21540 | 966 | 21760 | 1030 |
| 17 | 22720 | 1083 | 22390 | 1091 | 22280 | 939 | 22610 | 929 |
| 18 | 23670 | 1174 | 22790 | 1004 | 23070 | 994 | 23310 | 1026 |
| 19 | 24360 | 1214 | 23430 | 1180 | 23740 | 1083 | 24260 | 1006 |
| 20 | 25130 | 1238 | 24240 | 916 | 24580 | 1225 | 24760 | 643 |
| 21 | 25820 | 1300 | 24870 | 1204 | 25600 | 1145 | 25250 | 485 |
| 22 | 26760 | 1281 | 25490 | 1272 | 26450 | 1169 | 24890 | 254 |
| 23 | 27580 | 1170 | 26160 | 1344 | 26790 | 1200 | 24290 | 44 |
| 24 | 28030 | 1053 | 27580 | 1269 | 28070 | 1191 | 23890 | 351 |
| 25 | 28220 | 1087 | 28200 | 1334 | 28790 | 1049 | 24070 | 853 |
| 26 | 29050 | 1253 | 29140 | 1146 | 29340 | 1290 | 25470 | 1175 |
| 27 | 29980 | | 30060 | | 30180 | | 26770 | 1352 |
| 28 | | | | | | | 27420 | 1332 |
| 29 | | | | | | | 28500 | 1404 |
| 30 | | | | | | | 29140 | 1227 |
| 31 | | | | | | | 29660 | |

## B. Liveweight and Feed Intake Data - Experiment 2

1-40 = Pig Identity; M or F = Sex; LWT = Liveweight (g); FI = Feed Intake (g); L, $M_p$. $M_F$, $H_p$ or $H_F$ = Feed.

| ON | 20M LWT | 20FI L | 20FI HP | 33F LWT | 33FI L | 33FI HP | 21M LWT | 21FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 11820 | 400 | 96 | 12100 | 470 | 64 | 12330 | 422 |
| 2 | 12190 | 500 | 22 | 12330 | 594 | 8 | 12370 | 591 |
| 3 | 12330 | 655 | 11 | 12710 | 571 | 8 | 12880 | 440 |
| 4 | 12990 | 684 | 19 | 12970 | 690 | 0 | 13350 | 617 |
| 5 | 13310 | 268 | 445 | 13420 | 892 | 46 | 14010 | 788 |
| 6 | 14070 | 102 | 529 | 14100 | 1053 | 5 | 14650 | 622 |
| 7 | 14170 | 207 | 465 | 14740 | 200 | 534 | 15130 | 700 |
| 8 | 14980 | 225 | 445 | 15020 | 300 | 335 | 16050 | 441 |
| 9 | 15720 | 400 | 275 | 15320 | 779 | 1 | 16330 | 453 |
| 10 | 16370 | 385 | 442 | 16090 | 927 | 114 | 17650 | 342 |
| 11 | 16930 | 431 | 290 | 16790 | 958 | 97 | 18570 | 357 |
| 12 | 17560 | 328 | 490 | 17290 | 968 | 143 | 18890 | 173 |
| 13 | 18370 | 371 | 480 | 17890 | 937 | 315 | 18990 | 314 |
| 14 | 18810 | 500 | 510 | 18860 | 760 | 196 | 19830 | 326 |
| 15 | 19700 | 550 | 525 | 19370 | 640 | 240 | 20500 | 372 |
| 16 | 20200 | 348 | 601 | 19790 | 757 | 166 | 21450 | 297 |
| 17 | 21170 | 596 | 519 | 20380 | 813 | 243 | 22390 | 410 |
| 18 | 21970 | 534 | 494 | 20940 | 908 | 100 | 23210 | 506 |
| 19 | 22770 | 393 | 411 | 21430 | 953 | 222 | 24090 | 432 |
| 20 | 22970 | 468 | 484 | 22020 | 696 | 75 | 24780 | 510 |
| 21 | 23810 | 471 | 407 | 22140 | 840 | 232 | 25590 | 491 |
| 22 | 24350 | 701 | 496 | 23120 | 731 | 121 | 26120 | 398 |
| 23 | 25070 | 867 | 394 | 23670 | 844 | 405 | 26800 | 557 |
| 24 | 26390 | 719 | 538 | 24260 | 846 | 192 | 27570 | 633 |
| 25 | 26860 | 786 | 472 | 24960 | 911 | 275 | 28030 | 377 |
| 26 | 27650 | 849 | 383 | 25810 | 827 | 407 | 28640 | 600 |
| 27 | 28550 | 897 | 386 | 26440 | 994 | 297 | 29160 | 552 |
| 28 | 29250 | 874 | 388 | 27340 | 831 | 368 | 29860 | 589 |
| 29 | 30630 | | | 28220 | 914 | 512 | 31210 | |
| 30 | | | | 28990 | 832 | 401 | | |
| 31 | | | | 29630 | 975 | 337 | | |
| 32 | | | | 30630 | | | | |

| ROW | 21FI HP | 18F LWT | 18FI L | 18FI HP | 6M LWT | 6FI L | 6FI HF | 31M LWT |
|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 12000 | 82 | 445 | 11850 | 600 | 6 | 11700 |
| 2 | 11 | 12460 | 62 | 434 | 12220 | 696 | 3 | 11700 |
| 3 | 239 | 12770 | 150 | 486 | 12370 | 606 | 6 | 11790 |
| 4 | 180 | 13440 | 48 | 365 | 12800 | 726 | 4 | 11870 |
| 5 | 36 | 13970 | 91 | 599 | 13230 | 725 | 2 | 12030 |
| 6 | 234 | 14230 | 93 | 554 | 13700 | 758 | 2 | 11960 |
| 7 | 266 | 14870 | 100 | 638 | 14000 | 605 | 4 | 12480 |
| 8 | 447 | 15370 | 157 | 609 | 14240 | 489 | 2 | 12810 |
| 9 | 540 | 15820 | 103 | 515 | 14540 | 643 | 2 | 13120 |
| 10 | 664 | 16650 | 103 | 383 | 14770 | 852 | 1 | 13450 |
| 11 | 393 | 16900 | 325 | 631 | 15210 | 873 | 0 | 14020 |
| 12 | 400 | 17720 | 338 | 507 | 15550 | 872 | 0 | 14220 |
| 13 | 401 | 18120 | 458 | 488 | 16300 | 780 | 0 | 14430 |
| 14 | 437 | 18640 | 515 | 320 | 16680 | 838 | 3 | 15300 |
| 15 | 543 | 19490 | 380 | 471 | 17070 | 963 | 0 | 15740 |
| 16 | 610 | 19740 | 527 | 282 | 17390 | 1055 | 1 | 15320 |
| 17 | 742 | 20350 | 542 | 441 | 18100 | 1065 | 1 | 15360 |
| 18 | 600 | 20710 | 606 | 371 | 18760 | 1111 | 2 | 16720 |
| 19 | 493 | 21330 | 749 | 476 | 19220 | 1069 | 0 | 17160 |
| 20 | 582 | 22490 | 587 | 312 | 19950 | 1075 | 1 | 17580 |
| 21 | 482 | 22740 | 606 | 500 | 20590 | 1107 | 0 | 17780 |
| 22 | 554 | 23660 | 384 | 519 | 21070 | 1154 | 2 | 18570 |
| 23 | 529 | 24400 | 477 | 677 | 21380 | 1153 | 8 | 18920 |
| 24 | 430 | 24610 | 530 | 678 | 21980 | 1172 | 15 | 19630 |
| 25 | 477 | 25500 | 659 | 571 | 22320 | 1145 | 6 | 20240 |
| 26 | 469 | 26080 | 535 | 658 | 23020 | 1229 | 11 | 20750 |
| 27 | 515 | 26580 | 577 | 578 | 23740 | 1237 | 25 | 21410 |
| 28 | 494 | 27430 | 668 | 500 | 24220 | 1149 | 21 | 22200 |
| 29 | | 28050 | 630 | 547 | 25060 | 1245 | 8 | 22720 |
| 30 | | 28910 | 650 | 651 | 25490 | 1119 | 8 | 23230 |
| 31 | | 29540 | 566 | 767 | 25930 | 1170 | 0 | 23160 |
| 32 | | 29950 | 554 | 826 | 26720 | 1258 | 0 | 23780 |
| 33 | | 30720 | | | 27520 | 1124 | 7 | 24630 |
| 34 | | | | | 28250 | 1012 | 4 | 25260 |
| 35 | | | | | 28700 | 1128 | 0 | 25710 |
| 36 | | | | | 29300 | 1191 | 0 | 27030 |
| 37 | | | | | 29540 | 1222 | 2 | 27530 |
| 38 | | | | | 30230 | | | 28190 |
| 39 | | | | | | | | 29080 |
| 40 | | | | | | | | 29780 |

| ROW | 31FI L | 31FI HF | 26F LWT | 26FI L | 26FI HF | 1F LWT | 1FI L | 1FI HF |
|---|---|---|---|---|---|---|---|---|
| 1 | 404 | 18 | 11910 | 160 | 380 | 12400 | 145 | 6 |
| 2 | 421 | 4 | 12150 | 70 | 547 | 11560 | 500 | 356 |
| 3 | 443 | 4 | 12650 | 124 | 453 | 12690 | 64 | 451 |
| 4 | 488 | 6 | 13330 | 104 | 433 | 13130 | 85 | 621 |
| 5 | 394 | 7 | 13740 | 338 | 494 | 13640 | 0 | 675 |
| 6 | 509 | 4 | 14780 | 255 | 453 | 14260 | 781 | 403 |
| 7 | 567 | 2 | 15550 | 336 | 359 | 15580 | 902 | 15 |
| 8 | 556 | 9 | 16040 | 190 | 299 | 16670 | 1064 | 5 |
| 9 | 645 | 7 | 16350 | 153 | 375 | 17170 | 722 | 209 |
| 10 | 653 | 6 | 16410 | 221 | 533 | 17450 | 482 | 365 |
| 11 | 577 | 24 | 17500 | 277 | 558 | 17830 | 630 | 352 |
| 12 | 706 | 14 | 18270 | 327 | 431 | 18520 | 583 | 390 |
| 13 | 647 | 36 | 18770 | 339 | 411 | 19530 | 693 | 519 |
| 14 | 657 | 27 | 19390 | 288 | 397 | 20140 | 788 | 381 |
| 15 | 100 | 212 | 20030 | 277 | 482 | 21390 | 916 | 316 |
| 16 | 0 | 329 | 20350 | 417 | 461 | 22120 | 874 | 432 |
| 17 | 767 | 2 | 21240 | 477 | 494 | 22980 | 837 | 321 |
| 18 | 794 | 2 | 21890 | 459 | 403 | 23640 | 921 | 211 |
| 19 | 851 | 2 | 22470 | 526 | 511 | 24370 | 906 | 237 |
| 20 | 890 | 3 | 23800 | 490 | 411 | 24470 | 716 | 288 |
| 21 | 811 | 6 | 24580 | 460 | 428 | 25200 | 768 | 286 |
| 22 | 940 | 4 | 24760 | 378 | 373 | 25720 | 950 | 454 |
| 23 | 1018 | 4 | 25420 | 412 | 573 | 26860 | 1013 | 340 |
| 24 | 1019 | 2 | 25900 | 464 | 515 | 27960 | 1112 | 255 |
| 25 | 1162 | 4 | 26630 | 584 | 590 | 28640 | 1058 | 260 |
| 26 | 1116 | 3 | 27370 | 513 | 449 | 29640 | 1063 | 347 |
| 27 | 1212 | 4 | 28280 | 601 | 490 | 30210 | | |
| 28 | 1214 | 10 | 29020 | 749 | 496 | | | |
| 29 | 965 | 4 | 30090 | | | | | |
| 30 | 648 | 3 | | | | | | |
| 31 | 961 | 10 | | | | | | |
| 32 | 1328 | 28 | | | | | | |
| 33 | 1195 | 14 | | | | | | |
| 34 | 1248 | 6 | | | | | | |
| 35 | 1333 | 16 | | | | | | |
| 36 | 1461 | 13 | | | | | | |
| 37 | 1508 | 12 | | | | | | |
| 38 | 1467 | 14 | | | | | | |
| 39 | 1448 | 8 | | | | | | |

| ROW | 3M LWT | 3FI MP | 3FI HF | 25M LWT | 25FI MP | 25FI HF | 35F LWT | 35FI MP |
|---|---|---|---|---|---|---|---|---|
| 1 | 11880 | 490 | 6 | 11900 | 361 | 7 | 12250 | 288 |
| 2 | 12100 | 606 | 2 | 11860 | 648 | 8 | 12660 | 420 |
| 3 | 12640 | 570 | 4 | 12690 | 706 | 14 | 13200 | 496 |
| 4 | 12950 | 578 | 3 | 13270 | 853 | 14 | 13590 | 452 |
| 5 | 13410 | 596 | 4 | 14620 | 716 | 89 | 13900 | 548 |
| 6 | 13750 | 580 | 3 | 15240 | 767 | 40 | 14220 | 580 |
| 7 | 14460 | 700 | 0 | 15730 | 633 | 12 | 14870 | 591 |
| 8 | 15030 | 799 | 10 | 16140 | 533 | 69 | 15350 | 649 |
| 9 | 15830 | 571 | 3 | 16600 | 706 | 78 | 15870 | 459 |
| 10 | 16150 | 731 | 2 | 17240 | 659 | 46 | 16240 | 476 |
| 11 | 16910 | 654 | 31 | 17890 | 580 | 64 | 16440 | 540 |
| 12 | 17450 | 684 | 172 | 18110 | 672 | 36 | 16940 | 596 |
| 13 | 18110 | 588 | 170 | 19020 | 625 | 58 | 17410 | 673 |
| 14 | 18600 | 710 | 50 | 19400 | 789 | 113 | 18000 | 701 |
| 15 | 19050 | 781 | 46 | 20290 | 952 | 24 | 18630 | 648 |
| 16 | 19810 | 757 | 100 | 21320 | 928 | 20 | 19150 | 686 |
| 17 | 20590 | 889 | 42 | 22170 | 876 | 45 | 20000 | 784 |
| 18 | 21360 | 1003 | 17 | 22630 | 920 | 103 | 20620 | 783 |
| 19 | 22300 | 691 | 59 | 23350 | 918 | 61 | 21140 | 668 |
| 20 | 22220 | 816 | 78 | 24070 | 886 | 25 | 21840 | 694 |
| 21 | 23250 | 870 | 85 | 25200 | 819 | 15 | 22380 | 654 |
| 22 | 24120 | 1090 | 75 | 25470 | 850 | 13 | 22740 | 730 |
| 23 | 24960 | 1089 | 23 | 26230 | 856 | 6 | 23730 | 829 |
| 24 | 25690 | 998 | 18 | 26350 | 759 | 38 | 24480 | 786 |
| 25 | 26760 | 1155 | 15 | 27340 | 928 | 117 | 24980 | 817 |
| 26 | 27390 | 976 | 14 | 28080 | 919 | 117 | 25750 | 735 |
| 27 | 27580 | 1069 | 48 | 28880 | 929 | 88 | 26450 | 781 |
| 28 | 28640 | 1071 | 23 | 30090 | | | 27280 | 483 |
| 29 | 29560 | 1208 | 86 | | | | 27650 | 671 |
| 30 | 30390 | | | | | | 28040 | 829 |
| 31 | | | | | | | 28460 | 983 |
| 32 | | | | | | | 29450 | |

| ROW | 35FI HF | 16F LWT | 16FI MP | 16FI HF | 28F LWT | 28FI MF | 28FI HF | 30M LWT |
|---|---|---|---|---|---|---|---|---|
| 1 | 299 | 12020 | 40 | 77 | 11980 | 494 | 50 | 11760 |
| 2 | 71 | 11520 | 4 | 511 | 12370 | 595 | 12 | 12380 |
| 3 | 56 | 12160 | 4 | 511 | 13170 | 477 | 15 | 13030 |
| 4 | 42 | 12980 | 5 | 650 | 13510 | 520 | 3 | 13770 |
| 5 | 18 | 13740 | 16 | 656 | 14030 | 611 | 8 | 14280 |
| 6 | 27 | 14430 | 8 | 573 | 14400 | 516 | 3 | 14940 |
| 7 | 16 | 14680 | 7 | 530 | 15340 | 574 | 4 | 15800 |
| 8 | 14 | 15360 | 4 | 633 | 15940 | 584 | 1 | 16380 |
| 9 | 3 | 15660 | 7 | 715 | 16360 | 359 | 107 | 16860 |
| 10 | 9 | 16520 | 13 | 649 | 16600 | 352 | 154 | 17490 |
| 11 | 21 | 17150 | 20 | 844 | 17320 | 506 | 9 | 18030 |
| 12 | 59 | 17850 | 8 | 863 | 17650 | 552 | 0 | 18430 |
| 13 | 54 | 18560 | 2 | 852 | 18160 | 733 | 3 | 19310 |
| 14 | 80 | 19190 | 9 | 839 | 19060 | 747 | 5 | 19820 |
| 15 | 98 | 19730 | 9 | 917 | 19340 | 580 | 3 | 20430 |
| 16 | 74 | 20400 | 4 | 925 | 19680 | 393 | 3 | 21340 |
| 17 | 56 | 21130 | 103 | 667 | 19560 | 652 | 2 | 21700 |
| 18 | 78 | 21500 | 0 | 959 | 20110 | 219 | 2 | 22460 |
| 19 | 107 | 22750 | 15 | 1031 | 19860 | 104 | 2 | 22930 |
| 20 | 96 | 22910 | 101 | 931 | 19360 | 383 | 0 | 23700 |
| 21 | 88 | 23960 | 29 | 1041 | 20140 | 415 | 1 | 24530 |
| 22 | 97 | 24580 | 55 | 861 | 20610 | 686 | 0 | 25090 |
| 23 | 115 | 25290 | 173 | 947 | 21050 | 965 | 0 | 25490 |
| 24 | 69 | 26010 | 314 | 1027 | 22080 | 1173 | 2 | 25890 |
| 25 | 150 | 27160 | 284 | 865 | 23100 | 1174 | 3 | 26650 |
| 26 | 236 | 27790 | 593 | 655 | 24260 | 1281 | 1 | 27010 |
| 27 | 162 | 28580 | 581 | 511 | 25120 | 1337 | 1 | 27740 |
| 28 | 94 | 29480 | 598 | 874 | 26230 | 1375 | 1 | 28740 |
| 29 | 52 | 29690 | 795 | 399 | 27300 | 1196 | 1 | 29400 |
| 30 | 55 | 30380 | | | 28150 | 1319 | 1 | 30520 |
| 31 | 188 | | | | 28660 | 1253 | 1 | |
| 32 | | | | | 30070 | 1297 | 2 | |
| 33 | | | | | 30740 | | | |

| ROW | 30FI MF | 30FI HP | 10M LWT | 10FI MF | 10FI HP | 11F LWT | 11FI MF | 11FI HP |
|---|---|---|---|---|---|---|---|---|
| 1 | 520 | 9 | 11950 | 600 | 66 | 11440 | 0 | 996 |
| 2 | 593 | 6 | 12710 | 692 | 3 | 13340 | 0 | 665 |
| 3 | 627 | 3 | 13630 | 712 | 8 | 13540 | 1 | 723 |
| 4 | 601 | 6 | 14230 | 891 | 7 | 14090 | 9 | 823 |
| 5 | 619 | 25 | 14970 | 656 | 2 | 14680 | 22 | 841 |
| 6 | 725 | 5 | 15500 | 790 | 0 | 15380 | 71 | 922 |
| 7 | 668 | 4 | 16040 | 907 | 2 | 16430 | 117 | 951 |
| 8 | 595 | 6 | 16980 | 800 | 0 | 17230 | 102 | 938 |
| 9 | 624 | 3 | 17450 | 842 | 2 | 18090 | 153 | 926 |
| 10 | 645 | 3 | 18100 | 917 | 2 | 18740 | 169 | 913 |
| 11 | 701 | 5 | 18810 | 875 | 0 | 19470 | 260 | 770 |
| 12 | 857 | 3 | 19240 | 917 | 0 | 20040 | 338 | 782 |
| 13 | 1103 | 3 | 19700 | 836 | 121 | 20990 | 233 | 884 |
| 14 | 833 | 5 | 20160 | 981 | 30 | 21910 | 313 | 838 |
| 15 | 865 | 1 | 20830 | 1130 | 0 | 22570 | 272 | 881 |
| 16 | 741 | 0 | 21310 | 1161 | 24 | 23110 | 218 | 895 |
| 17 | 879 | 2 | 22160 | 1262 | 0 | 23970 | 158 | 878 |
| 18 | 820 | 3 | 22960 | 1348 | 0 | 24470 | 126 | 1076 |
| 19 | 909 | 3 | 24620 | 1310 | 0 | 25350 | 74 | 1160 |
| 20 | 1008 | 3 | 25400 | 1213 | 0 | 26020 | 107 | 1093 |
| 21 | 944 | 0 | 26040 | 1142 | 0 | 26850 | 63 | 1067 |
| 22 | 957 | 3 | 26770 | 1151 | 0 | 27460 | 43 | 1137 |
| 23 | 706 | 3 | 27280 | 1233 | 1 | 28250 | 111 | 1077 |
| 24 | 987 | 15 | 28780 | 1060 | 2 | 28810 | 13 | 1080 |
| 25 | 1040 | 5 | 29000 | 1187 | 2 | 28710 | 61 | 1108 |
| 26 | 1106 | 4 | 29390 | | | 30000 | | |
| 27 | 1227 | 4 | | | | | | |
| 28 | 1112 | 4 | | | | | | |
| 29 | 1103 | 3 | | | | | | |

| ROW | 40F LWT | 40FI HP | 40FI HF | 36M LWT | 36FI HP | 36FI HF | 40M LWT | 40aFI HP |
|---|---|---|---|---|---|---|---|---|
| 1 | 11780 | 138 | 451 | 12670 | 419 | 206 | 12540 | 72 |
| 2 | 12450 | 179 | 429 | 13040 | 555 | 54 | 13250 | 4 |
| 3 | 12810 | 108 | 424 | 13540 | 541 | 55 | 14000 | 5 |
| 4 | 13300 | 96 | 427 | 14150 | 557 | 44 | 15060 | 3 |
| 5 | 13820 | 66 | 563 | 14690 | 668 | 16 | 15790 | 6 |
| 6 | 14370 | 360 | 251 | 15580 | 687 | 19 | 16450 | 1 |
| 7 | 14810 | 529 | 223 | 16080 | 692 | 81 | 17480 | 2 |
| 8 | 15340 | 380 | 329 | 17120 | 515 | 168 | 18320 | 2 |
| 9 | 16500 | 231 | 526 | 17680 | 553 | 95 | 19160 | 0 |
| 10 | 17190 | 406 | 451 | 18450 | 541 | 39 | 19780 | 2 |
| 11 | 17940 | 204 | 634 | 18970 | 287 | 271 | 20590 | 3 |
| 12 | 18490 | 231 | 570 | 19080 | 352 | 302 | 21690 | 3 |
| 13 | 19160 | 112 | 653 | 19980 | 339 | 538 | 22710 | 2 |
| 14 | 19810 | 87 | 744 | 20680 | 85 | 691 | 24030 | 1 |
| 15 | 20210 | 222 | 516 | 21480 | 56 | 777 | 25330 | 3 |
| 16 | 21130 | 542 | 352 | 22380 | 35 | 756 | 26030 | 3 |
| 17 | 21680 | 644 | 257 | 22720 | 9 | 889 | 26860 | 3 |
| 18 | 22070 | 674 | 243 | 23700 | 17 | 950 | 27890 | 1 |
| 19 | 22800 | 326 | 605 | 24180 | 108 | 769 | 27950 | 2 |
| 20 | 22980 | 326 | 489 | 24620 | 3 | 896 | 29300 | |
| 21 | 23480 | 300 | 401 | 25150 | 1 | 957 | | |
| 22 | 23630 | 218 | 520 | 26310 | 3 | 1018 | | |
| 23 | 24230 | 66 | 672 | 27030 | 0 | 1142 | | |
| 24 | 24850 | 202 | 752 | 27910 | 25 | 1072 | | |
| 25 | 25040 | 160 | 740 | 28590 | 1 | 1012 | | |
| 26 | 25430 | 314 | 746 | 29220 | 0 | 1155 | | |
| 27 | 26130 | 269 | 864 | 30050 | | | | |
| 28 | 26710 | 112 | 812 | | | | | |
| 29 | 27200 | 160 | 914 | | | | | |
| 30 | 28300 | 246 | 1032 | | | | | |
| 31 | 28870 | 272 | 1138 | | | | | |
| 32 | 29720 | 122 | 1224 | | | | | |
| 33 | 30360 | | | | | | | |

| ROW | 40aFI HF | 15F LWT | 15FI HP | 15FI HF | 4F LWT | 4FI L | 38F LWT | 38FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 722 | 11920 | 24 | 308 | 12160 | 473 | 12660 | 730 |
| 2 | 693 | 12230 | 3 | 325 | 12290 | 574 | 13210 | 771 |
| 3 | 855 | 12570 | 6 | 334 | 12470 | 534 | 13700 | 731 |
| 4 | 949 | 12870 | 60 | 354 | 12790 | 508 | 13910 | 598 |
| 5 | 887 | 13520 | 23 | 335 | 12790 | 544 | 13890 | 521 |
| 6 | 1072 | 13770 | 322 | 131 | 12860 | 595 | 14170 | 617 |
| 7 | 812 | 14160 | 459 | 23 | 13260 | 683 | 14290 | 643 |
| 8 | 1072 | 14760 | 581 | 6 | 13840 | 570 | 14810 | 796 |
| 9 | 986 | 15310 | 485 | 2 | 14000 | 477 | 15260 | 666 |
| 10 | 1188 | 15680 | 725 | 1 | 14220 | 586 | 15480 | 733 |
| 11 | 1282 | 16410 | 603 | 1 | 14470 | 570 | 15950 | 817 |
| 12 | 1355 | 16640 | 672 | 0 | 14820 | 670 | 16500 | 879 |
| 13 | 1422 | 17310 | 557 | 0 | 15100 | 699 | 16870 | 754 |
| 14 | 1475 | 18010 | 657 | 1 | 15550 | 613 | 17020 | 620 |
| 15 | 1501 | 18620 | 611 | 0 | 15700 | 703 | 17590 | 727 |
| 16 | 1281 | 18960 | 610 | 0 | 16200 | 649 | 18050 | 909 |
| 17 | 1251 | 19120 | 623 | 5 | 16450 | 624 | 18490 | 1022 |
| 18 | 1012 | 19380 | 796 | 7 | 16780 | 479 | 19120 | 1038 |
| 19 | 1423 | 20680 | 760 | 6 | 16850 | 515 | 19620 | 1101 |
| 20 | | 20870 | 685 | 3 | 16920 | 580 | 20220 | 1228 |
| 21 | | 22060 | 796 | 0 | 17050 | 731 | 21190 | 1133 |
| 22 | | 22030 | 739 | 2 | 17810 | 727 | 21480 | 1250 |
| 23 | | 22650 | 612 | 0 | 18170 | 660 | 22240 | 1304 |
| 24 | | 22950 | 788 | 3 | 18370 | 535 | 23190 | 1284 |
| 25 | | 23470 | 962 | 0 | 18420 | 689 | 23630 | 1228 |
| 26 | | 24830 | 787 | 21 | 18840 | 811 | 24130 | 1339 |
| 27 | | 25010 | 934 | 4 | 19140 | 714 | 24960 | 1371 |
| 28 | | 25830 | 870 | 0 | 19510 | 792 | 25680 | 1417 |
| 29 | | 26130 | 844 | 3 | 19890 | 829 | 26300 | 1230 |
| 30 | | 26470 | 800 | 4 | 20340 | 837 | 26570 | 1506 |
| 31 | | 26670 | 746 | 189 | 21030 | 926 | 27510 | 1458 |
| 32 | | 27840 | 855 | 12 | 21530 | 899 | 28180 | 1470 |
| 33 | | 28630 | 875 | 70 | 21900 | 879 | 28880 | 1519 |
| 34 | | 28780 | 627 | 250 | 22440 | 939 | 29580 | 1571 |
| 35 | | 30210 | | | 22670 | 895 | 30260 | |
| 36 | | | | | 23060 | 1044 | | |
| 37 | | | | | 23590 | 935 | | |
| 38 | | | | | 24340 | 914 | | |
| 39 | | | | | 24580 | 894 | | |
| 40 | | | | | 24880 | 912 | | |
| 41 | | | | | 25040 | 1038 | | |
| 42 | | | | | 26070 | 994 | | |
| 43 | | | | | 26100 | 1113 | | |
| 44 | | | | | 27110 | 1046 | | |
| 45 | | | | | 27230 | 979 | | |
| 46 | | | | | 27900 | 1150 | | |
| 47 | | | | | 28230 | 1194 | | |
| 48 | | | | | 29120 | 1125 | | |
| 49 | | | | | 29630 | | | |

| ROW | 9M LWT | 9FI L | 7M LWT | 7FI L | 24M LWT | 24FI MP | 14M LWT | 14FI MP |
|---|---|---|---|---|---|---|---|---|
| 1 | 12810 | 786 | 11990 | 590 | 11790 | 675 | 11810 | 465 |
| 2 | 13540 | 944 | 12110 | 800 | 12550 | 654 | 12100 | 600 |
| 3 | 13960 | 956 | 12560 | 762 | 13180 | 747 | 13030 | 688 |
| 4 | 14770 | 1092 | 12800 | 664 | 13720 | 724 | 13470 | 497 |
| 5 | 14950 | 1212 | 13280 | 900 | 14610 | 748 | 13690 | 520 |
| 6 | 15800 | 1321 | 13810 | 888 | 15080 | 562 | 14240 | 643 |
| 7 | 16730 | 1383 | 14030 | 605 | 15050 | 751 | 14350 | 622 |
| 8 | 17320 | 1351 | 14170 | 859 | 15820 | 543 | 15080 | 677 |
| 9 | 18070 | 1269 | 14830 | 988 | 16470 | 600 | 15640 | 633 |
| 10 | 18770 | 1357 | 15530 | 983 | 16980 | 700 | 16250 | 656 |
| 11 | 19430 | 1441 | 16150 | 668 | 17150 | 765 | 16550 | 827 |
| 12 | 20250 | 1467 | 16080 | 772 | 17780 | 1000 | 17480 | 814 |
| 13 | 20880 | 1511 | 16690 | 791 | 18900 | 1143 | 17970 | 683 |
| 14 | 21710 | 1457 | 16740 | 836 | 19860 | 979 | 18480 | 813 |
| 15 | 22370 | 1463 | 17300 | 1158 | 20580 | 970 | 19110 | 927 |
| 16 | 22710 | 1378 | 17960 | 961 | 21440 | 1020 | 19930 | 865 |
| 17 | 23290 | 1401 | 18690 | 1022 | 22260 | 861 | 20690 | 729 |
| 18 | 24050 | 1329 | 19090 | 1122 | 22740 | 945 | 20990 | 640 |
| 19 | 24530 | 1420 | 19720 | 1104 | 23040 | 1054 | 21250 | 832 |
| 20 | 25170 | 1321 | 20180 | 1179 | 24290 | 1131 | 21990 | 976 |
| 21 | 26010 | 1456 | 20880 | 1056 | 24910 | 1123 | 22890 | 1100 |
| 22 | 26390 | 1526 | 21430 | 1162 | 25790 | 1256 | 23750 | 968 |
| 23 | 27040 | 1453 | 22050 | 1140 | 26800 | 1320 | 24470 | 976 |
| 24 | 28100 | 1497 | 22890 | 1181 | 27420 | 441 | 25030 | 1031 |
| 25 | 28830 | 1400 | 23200 | 1125 | 27230 | 634 | 26210 | 1090 |
| 26 | 29400 | 1494 | 23790 | 1264 | 27500 | 229 | 26980 | 1025 |
| 27 | 30070 | | 24410 | 1310 | 26690 | 226 | 27510 | 1058 |
| 28 | | | 24880 | 1186 | 26060 | 188 | 28540 | 1068 |
| 29 | | | 25530 | 1351 | 25810 | 214 | 29000 | 982 |
| 30 | | | 26480 | 1258 | 25860 | 438 | 29590 | |
| 31 | | | 26660 | 1314 | 26330 | 842 | | |
| 32 | | | 27490 | 1273 | 27270 | 1005 | | |
| 33 | | | 28010 | 1233 | 28400 | 1575 | | |
| 34 | | | 28470 | 1231 | 30250 | | | |
| 35 | | | 29240 | 1275 | | | | |
| 36 | | | 29750 | 1255 | | | | |
| 37 | | | 29950 | | | | | |

| ROW | 12F LWT | 12FI MF | 37F LWT | 37FI MF | 13M LWT | 13FI MF | 27M LWT | 27FI MF |
|---|---|---|---|---|---|---|---|---|
| 1 | 11900 | 578 | 12460 | 800 | 12250 | 543 | 12240 | 429 |
| 2 | 12120 | 872 | 12980 | 972 | 12870 | 661 | 12560 | 532 |
| 3 | 12780 | 902 | 13840 | 724 | 13740 | 788 | 12970 | 644 |
| 4 | 13780 | 923 | 14050 | 893 | 14390 | 675 | 13680 | 594 |
| 5 | 14360 | 928 | 14880 | 799 | 14890 | 579 | 14290 | 480 |
| 6 | 15310 | 759 | 15410 | 990 | 15190 | 657 | 14750 | 547 |
| 7 | 15860 | 816 | 16280 | 1100 | 15940 | 714 | 15260 | 657 |
| 8 | 16400 | 823 | 17180 | 1249 | 16200 | 676 | 16050 | 520 |
| 9 | 16820 | 751 | 18480 | 946 | 16790 | 816 | 16690 | 619 |
| 10 | 17600 | 871 | 19120 | 1130 | 17590 | 871 | 17070 | 667 |
| 11 | 18130 | 842 | 19810 | 1228 | 18390 | 736 | 17750 | 669 |
| 12 | 18700 | 868 | 20690 | 1257 | 19050 | 789 | 18420 | 714 |
| 13 | 19100 | 951 | 21810 | 1162 | 19760 | 707 | 19110 | 762 |
| 14 | 19860 | 919 | 22580 | 941 | 20230 | 748 | 19740 | 763 |
| 15 | 20630 | 866 | 23080 | 769 | 20800 | 871 | 20440 | 739 |
| 16 | 21190 | 842 | 23660 | 932 | 21470 | 954 | 21100 | 800 |
| 17 | 22250 | 1012 | 24360 | 1083 | 22180 | 996 | 21820 | 968 |
| 18 | 22750 | 1123 | 25160 | 1188 | 23200 | 1014 | 22650 | 952 |
| 19 | 23560 | 1164 | 26040 | 1390 | 24290 | 996 | 23510 | 982 |
| 20 | 24310 | 1157 | 26740 | 1480 | 24940 | 1025 | 24340 | 960 |
| 21 | 25160 | 1294 | 27960 | 1567 | 25710 | 1117 | 24880 | 892 |
| 22 | 26010 | 1219 | 29170 | 1468 | 26360 | 1088 | 25560 | 1062 |
| 23 | 26890 | 1131 | 30380 | | 27210 | 1086 | 26430 | 944 |
| 24 | 27460 | 1190 | | | 28060 | 1133 | 26660 | 958 |
| 25 | 28150 | 1056 | | | 28890 | 1193 | 27790 | 953 |
| 26 | 28850 | 1108 | | | 29790 | | 28050 | 1005 |
| 27 | 29680 | 1179 | | | | | 28780 | 1186 |
| 28 | 30240 | | | | | | 29900 | |

| ROW | 4aF LWT | 4FI MF | 29F LWT | 29FI MF | 19M LWT | 19FI HP | 17M LWT | 17FI HP |
|---|---|---|---|---|---|---|---|---|
| 1 | 11880 | 558 | 11770 | 580 | 12170 | 62 | 11860 | 354 |
| 2 | 12360 | 744 | 12160 | 790 | 11270 | 581 | 12220 | 362 |
| 3 | 12660 | 920 | 13060 | 858 | 12690 | 633 | 12530 | 529 |
| 4 | 13540 | 760 | 13900 | 717 | 13090 | 631 | 13190 | 575 |
| 5 | 14320 | 668 | 14640 | 739 | 13840 | 685 | 13820 | 569 |
| 6 | 14790 | 733 | 15170 | 587 | 14540 | 751 | 14210 | 520 |
| 7 | 15430 | 779 | 15780 | 717 | 15510 | 818 | 14910 | 539 |
| 8 | 16090 | 952 | 16320 | 861 | 16450 | 874 | 15300 | 534 |
| 9 | 17020 | 860 | 17200 | 944 | 17180 | 779 | 15890 | 557 |
| 10 | 17350 | 846 | 17810 | 878 | 17780 | 477 | 16430 | 576 |
| 11 | 18030 | 870 | 18800 | 935 | 17900 | 790 | 16730 | 550 |
| 12 | 18380 | 1005 | 19420 | 834 | 18660 | 750 | 17360 | 520 |
| 13 | 19300 | 938 | 20270 | 723 | 19160 | 318 | 17660 | 568 |
| 14 | 20050 | 768 | 20790 | 876 | 18800 | 282 | 18090 | 679 |
| 15 | 20470 | 709 | 21430 | 965 | 18750 | 305 | 18800 | 696 |
| 16 | 20830 | 885 | 21780 | 1054 | 18750 | 775 | 19190 | 671 |
| 17 | 21530 | 1065 | 22380 | 1111 | 19800 | 858 | 19620 | 758 |
| 18 | 22150 | 1144 | 23680 | 1102 | 20660 | 804 | 20280 | 675 |
| 19 | 23550 | 1177 | 24530 | 1066 | 21230 | 864 | 20610 | 752 |
| 20 | 23770 | 1109 | 25060 | 1142 | 21930 | 974 | 21470 | 704 |
| 21 | 24580 | 1164 | 25870 | 1182 | 22690 | 931 | 21920 | 811 |
| 22 | 25390 | 1219 | 26850 | 830 | 23690 | 946 | 22950 | 918 |
| 23 | 26010 | 1203 | 27330 | 1089 | 24330 | 884 | 23770 | 652 |
| 24 | 27070 | 1215 | 27960 | 1256 | 24790 | 899 | 23840 | 660 |
| 25 | 27670 | 1049 | 28760 | 1337 | 25190 | 1066 | 24120 | 370 |
| 26 | 28380 | 1339 | 29950 | | 25970 | 697 | 24540 | 838 |
| 27 | 29430 | | | | 26110 | 721 | 24920 | 1024 |
| 28 | | | | | 26660 | 367 | 25820 | 1076 |
| 29 | | | | | 26160 | 973 | 26510 | 1214 |
| 30 | | | | | 27310 | 1275 | 27480 | 1152 |
| 31 | | | | | 28260 | 1359 | 28200 | 1078 |
| 32 | | | | | 29320 | 1463 | 28910 | 995 |
| 33 | | | | | 30260 | | 29940 | |

| ROW | 32F LWT | 32FI HP | 22F LWT | 22FI HP | 39M LWT | 39FI HF | 8M LWT | 8FI HF |
|---|---|---|---|---|---|---|---|---|
| 1 | 11990 | 262 | 12870 | 374 | 11800 | 502 | 12040 | 316 |
| 2 | 11820 | 486 | 13030 | 305 | 12140 | 464 | 12050 | 588 |
| 3 | 12450 | 383 | 13340 | 360 | 12520 | 357 | 12830 | 494 |
| 4 | 12700 | 543 | 13860 | 538 | 12980 | 345 | 13380 | 574 |
| 5 | 13460 | 576 | 14430 | 454 | 13220 | 547 | 13910 | 479 |
| 6 | 14110 | 566 | 14700 | 625 | 13960 | 602 | 14250 | 660 |
| 7 | 14460 | 530 | 15250 | 611 | 14510 | 645 | 15020 | 590 |
| 8 | 15060 | 659 | 16050 | 749 | 15400 | 626 | 15730 | 618 |
| 9 | 15550 | 650 | 16700 | 638 | 15900 | 776 | 16510 | 593 |
| 10 | 16330 | 636 | 17290 | 702 | 16850 | 680 | 16980 | 691 |
| 11 | 17260 | 697 | 17780 | 630 | 17350 | 791 | 17500 | 762 |
| 12 | 17630 | 453 | 18280 | 553 | 18340 | 872 | 18510 | 709 |
| 13 | 17810 | 474 | 18580 | 402 | 18960 | 829 | 18730 | 122 |
| 14 | 18170 | 655 | 18500 | 580 | 19840 | 724 | 18190 | 304 |
| 15 | 18880 | 659 | 18890 | 395 | 20180 | 853 | 17980 | 387 |
| 16 | 19210 | 725 | 18680 | 608 | 21080 | 880 | 18680 | 569 |
| 17 | 19910 | 823 | 19290 | 781 | 21850 | 818 | 19340 | 756 |
| 18 | 20750 | 839 | 19910 | 704 | 22520 | 639 | 19980 | 651 |
| 19 | 21510 | 748 | 20750 | 683 | 22600 | 616 | 20280 | 564 |
| 20 | 22030 | 851 | 21200 | 715 | 22920 | 633 | 20630 | 660 |
| 21 | 22860 | 886 | 21440 | 754 | 23140 | 895 | 21360 | 606 |
| 22 | 23310 | 789 | 21990 | 894 | 24540 | 1154 | 21700 | 845 |
| 23 | 23750 | 681 | 22520 | 673 | 25550 | 1166 | 22370 | 604 |
| 24 | 23850 | 625 | 22830 | 914 | 26620 | 1026 | 22860 | 802 |
| 25 | 23870 | 711 | 23440 | 648 | 27470 | 1140 | 23710 | 942 |
| 26 | 24830 | 768 | 23650 | 574 | 28050 | 1177 | 24230 | 826 |
| 27 | 25490 | 863 | 23930 | 957 | 28760 | 1230 | 25160 | 844 |
| 28 | 26050 | 1133 | 24740 | 922 | 29690 | | 26230 | 990 |
| 29 | 26590 | 1118 | 25450 | 870 | | | 26930 | 906 |
| 30 | 27420 | 1152 | 26150 | 781 | | | 27450 | 874 |
| 31 | 28200 | 1326 | 26080 | 989 | | | 28160 | 1195 |
| 32 | 29040 | 1215 | 26960 | 1018 | | | 29500 | 1115 |
| 33 | 30000 | | 27570 | 565 | | | 30290 | |
| 34 | | | 27330 | 682 | | | | |
| 35 | | | 27470 | 677 | | | | |
| 36 | | | 28230 | 1048 | | | | |
| 37 | | | 28690 | 500 | | | | |
| 38 | | | 28950 | 1113 | | | | |
| 39 | | | 29660 | | | | | |

| ROW | 34F LWT | 34FI HF | 2F LWT | 2FI HF |
|---|---|---|---|---|
| 1 | 12220 | 371 | 11720 | 290 |
| 2 | 12240 | 465 | 11790 | 528 |
| 3 | 12510 | 544 | 12330 | 387 |
| 4 | 13130 | 542 | 12510 | 540 |
| 5 | 13640 | 587 | 13090 | 622 |
| 6 | 14190 | 566 | 13810 | 689 |
| 7 | 14720 | 451 | 14380 | 596 |
| 8 | 14800 | 441 | 15140 | 699 |
| 9 | 15110 | 583 | 15730 | 665 |
| 10 | 15760 | 262 | 16140 | 737 |
| 11 | 15750 | 509 | 16850 | 760 |
| 12 | 16360 | 506 | 17210 | 783 |
| 13 | 16630 | 484 | 17940 | 799 |
| 14 | 16970 | 342 | 18860 | 721 |
| 15 | 16920 | 500 | 18860 | 708 |
| 16 | 17260 | 575 | 19390 | 947 |
| 17 | 17900 | 800 | 20250 | 752 |
| 18 | 18470 | 767 | 20600 | 806 |
| 19 | 18910 | 836 | 21230 | 841 |
| 20 | 19740 | 616 | 21490 | 797 |
| 21 | 20260 | 606 | 22370 | 929 |
| 22 | 20860 | 440 | 23000 | 1005 |
| 23 | 20760 | 280 | 23430 | 770 |
| 24 | 20670 | 509 | 24240 | 1104 |
| 25 | 21110 | 504 | 25480 | 1123 |
| 26 | 21610 | 800 | 26080 | 1081 |
| 27 | 22210 | 809 | 26750 | 1044 |
| 28 | 23060 | 847 | 27450 | 1203 |
| 29 | 23720 | 931 | 28190 | 945 |
| 30 | 24780 | 872 | 28250 | 1317 |
| 31 | 25300 | 878 | 29600 | 1196 |
| 32 | 25920 | 802 | 30090 | |
| 33 | 26330 | 925 | | |
| 34 | 26710 | 898 | | |
| 35 | 27520 | 971 | | |
| 36 | 28330 | 824 | | |
| 37 | 28730 | 1132 | | |
| 38 | 29650 | 1141 | | |
| 39 | 30370 | | | |

## C. Liveweight and Feed Intake Data - Experiment 3

1-40 = Pig Identity; M or F = Sex; LWT = Liveweight (g); FI = Feed Intake (g); L, A, B or H = Feed.

| ROW | 23M LWT | 23FI L | 23FI H | 15M LWT | 15FI L | 15FI H | 18M LWT | 18FI L | 18FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11980 | 348 | * | 12610 | * | 554 | 12140 | 498 | * |
| 2 | 11890 | * | 766 | 13060 | 619 | * | 12300 | * | 673 |
| 3 | 12870 | 698 | * | 13480 | * | 603 | 13210 | 770 | * |
| 4 | 13150 | * | 829 | 14010 | 491 | * | 13790 | * | 773 |
| 5 | 14080 | 704 | * | 14160 | * | 532 | 14330 | 788 | * |
| 6 | 14370 | * | 898 | 14760 | 650 | * | 14930 | * | 729 |
| 7 | 15310 | 4 | 788 | 14980 | 80 | 591 | 15510 | 688 | 61 |
| 8 | 15880 | 58 | 856 | 15890 | 131 | 742 | 16320 | 96 | 612 |
| 9 | 16720 | 6 | 838 | 16730 | 164 | 680 | 17060 | 83 | 585 |
| 10 | 17560 | 47 | 726 | 17470 | 68 | 729 | 17540 | 146 | 596 |
| 11 | 18160 | 9 | 662 | 18260 | 195 | 684 | 18260 | 74 | 664 |
| 12 | 18970 | 6 | 885 | 19100 | 87 | 784 | 18870 | 92 | 706 |
| 13 | 19780 | 349 | 600 | 19900 | 221 | 647 | 19770 | 62 | 745 |
| 14 | 20490 | 193 | 816 | 20650 | 233 | 795 | 20410 | 165 | 709 |
| 15 | 21350 | 252 | 722 | 21540 | 394 | 534 | 21080 | 191 | 642 |
| 16 | 22250 | 412 | 790 | 22200 | 319 | 636 | 22050 | 210 | 709 |
| 17 | 22890 | 512 | 533 | 22850 | 418 | 584 | 22480 | 194 | 724 |
| 18 | 23860 | 453 | 733 | 23790 | 258 | 692 | 23200 | 242 | 594 |
| 19 | 24620 | * | 937 | 24460 | 807 | * | 23610 | * | 974 |
| 20 | 25670 | 1079 | * | 24410 | * | 987 | 24380 | 1070 | * |
| 21 | 25970 | * | 934 | 25920 | 1084 | * | 25240 | * | 916 |
| 22 | 26890 | 1158 | * | 26180 | * | 962 | 25990 | 1150 | * |
| 23 | 27350 | * | 1096 | 27250 | 1063 | * | 26650 | * | 1019 |
| 24 | 28090 | 1370 | * | 27960 | * | 1009 | 27650 | 1333 | * |
| 25 | 28590 | 406 | 686 | 29020 | 654 | 428 | 28130 | 567 | 514 |
| 26 | * | 339 | 572 | * | 748 | 569 | * | 587 | 713 |
| 27 | * | 650 | 653 | 30720 | 788 | 446 | 29850 | 588 | 610 |
| 28 | 31060 | 409 | 595 | * | 662 | 751 | * | 753 | 479 |
| 29 | * | 424 | 821 | * | 714 | 588 | * | 973 | 413 |
| 30 | * | 568 | 658 | 33570 | 842 | 647 | 32180 | 898 | 380 |
| 31 | 33390 | 639 | 704 | * | 900 | 650 | * | 1109 | 457 |
| 32 | * | 1123 | 97 | * | 636 | 670 | * | 1144 | 301 |
| 33 | * | 740 | 503 | * | 824 | 345 | * | 1116 | 308 |
| 34 | * | 717 | 583 | 37340 | 662 | 648 | 35650 | 827 | 399 |
| 35 | 36270 | 828 | 503 | * | 684 | 540 | * | 776 | 527 |
| 36 | * | 859 | 586 | * | 389 | 649 | * | 900 | 382 |
| 37 | 37910 | | | 39540 | | | 37500 | | |

| ROW | 20F LWT | 20FI L | 20FI H | 22F LWT | 22FI L | 22FI H | 39F LWT | 39FI L | 39FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11790 | * | 700 | 12090 | * | 652 | 12110 | 269 | * |
| 2 | 12420 | 780 | * | 12590 | 677 | * | 11670 | * | 668 |
| 3 | 13020 | * | 551 | 12790 | * | 692 | 12660 | 763 | * |
| 4 | 13250 | 639 | * | 13460 | 748 | * | 13150 | * | 784 |
| 5 | 13880 | * | 191 | 13850 | * | 771 | 13990 | 926 | * |
| 6 | 13550 | 493 | * | 14660 | 913 | * | 14690 | * | 809 |
| 7 | 13800 | 616 | 40 | 15260 | 9 | 780 | 15860 | 114 | 890 |
| 8 | 14380 | 654 | 28 | 15830 | 0 | 916 | 16640 | 6 | 1041 |
| 9 | 14540 | 629 | 24 | 16610 | 54 | 841 | 17570 | 5 | 984 |
| 10 | 14900 | 418 | 571 | 17580 | 0 | 861 | 18360 | 12 | 996 |
| 11 | 15880 | 606 | 89 | 18380 | 189 | 860 | 19480 | 23 | 1064 |
| 12 | 16320 | 460 | 362 | 18820 | 2 | 965 | 20220 | 29 | 986 |
| 13 | 16930 | 372 | 616 | 19990 | 0 | 958 | 20920 | 169 | 659 |
| 14 | 17990 | 330 | 555 | 20540 | 0 | 910 | 21690 | 525 | 552 |
| 15 | 18280 | 430 | 387 | 21310 | 0 | 1011 | 22480 | 608 | 395 |
| 16 | 18820 | 448 | 600 | 22340 | 457 | 694 | 23040 | 360 | 665 |
| 17 | 19720 | 379 | 564 | 22980 | 529 | 640 | 23610 | 682 | 458 |
| 18 | 20420 | 318 | 775 | 23580 | 874 | 167 | 24550 | 581 | 550 |
| 19 | 21200 | 925 | * | 24170 | 1341 | * | 25430 | * | 1007 |
| 20 | 21730 | * | 1149 | 24710 | * | 1079 | 25990 | 1084 | * |
| 21 | 22370 | 1034 | * | 25310 | 1326 | * | 26940 | * | 1044 |
| 22 | 23330 | * | 1098 | 26220 | * | 1217 | 27680 | 1155 | * |
| 23 | 23930 | 1337 | * | 26540 | 1116 | * | 28440 | * | 1146 |
| 24 | 24670 | * | 933 | 27470 | * | 1098 | 29320 | 1186 | * |
| 25 | 25290 | 628 | 773 | 28320 | | | 29590 | 368 | 809 |
| 26 | * | 469 | 803 | | | | * | 381 | 918 |
| 27 | * | 608 | 629 | | | | * | 966 | 225 |
| 28 | 28240 | 629 | 636 | | | | 32710 | 861 | 479 |
| 29 | * | 714 | 668 | | | | * | 920 | 556 |
| 30 | * | 952 | 614 | | | | * | 923 | 266 |
| 31 | 30600 | 744 | 525 | | | | 34150 | 956 | 128 |
| 32 | * | 1023 | 410 | | | | * | 1061 | 250 |
| 33 | * | 878 | 440 | | | | * | 1189 | 265 |
| 34 | * | 996 | 568 | | | | * | 1144 | 279 |
| 35 | 33900 | 1287 | 342 | | | | 36810 | | |
| 36 | * | 1173 | 591 | | | | | | |
| 37 | 35640 | | | | | | | | |

| ROW | 1M LWT | 1FI L | 1FI H | 27M LWT | 27FI L | 27FI H | 33F LWT | 33FI L | 33FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12120 | 358 | * | 12050 | 332 | * | 12080 | 739 | * |
| 2 | 12080 | 471 | * | 12050 | 485 | * | 12800 | 741 | * |
| 3 | 12640 | 563 | * | 12460 | 526 | * | 13250 | 804 | * |
| 4 | 12960 | 487 | * | 12710 | 683 | * | 13720 | 930 | * |
| 5 | 13090 | 628 | * | 13120 | 647 | * | 14090 | 922 | * |
| 6 | 13240 | 588 | * | 13430 | 650 | * | 14370 | 858 | * |
| 7 | 13690 | 4 | 725 | 13910 | 5 | 727 | 14900 | 150 | 810 |
| 8 | 14670 | 0 | 767 | 14680 | 78 | 732 | 15980 | 86 | 849 |
| 9 | 15390 | 20 | 850 | 15700 | 254 | 556 | 16580 | 136 | 655 |
| 10 | 16220 | 2 | 748 | 16170 | 4 | 749 | 17060 | 111 | 522 |
| 11 | 16820 | 0 | 681 | 16770 | 5 | 763 | 16930 | 93 | 566 |
| 12 | 17800 | 227 | 513 | 17760 | 72 | 787 | 18080 | 131 | 839 |
| 13 | 18060 | 110 | 644 | 18610 | 9 | 685 | 18990 | 460 | 658 |
| 14 | 18740 | 303 | 500 | 19230 | 36 | 535 | 19960 | 370 | 815 |
| 15 | 19460 | 221 | 571 | 19680 | 3 | 794 | 21080 | 228 | 710 |
| 16 | 20220 | 423 | 538 | 20420 | 8 | 766 | 21860 | 340 | 655 |
| 17 | 20880 | 121 | 614 | 21090 | 78 | 681 | 22030 | 388 | 703 |
| 18 | 21300 | 555 | 478 | 21960 | 39 | 816 | 22920 | 625 | 460 |
| 19 | 22110 | * | 917 | 22660 | * | 938 | 23480 | * | 966 |
| 20 | 23150 | * | 958 | 23360 | * | 946 | 24250 | * | 1019 |
| 21 | 24050 | * | 995 | 24700 | * | 933 | 24640 | * | 973 |
| 22 | 25020 | * | 1028 | 25210 | * | 917 | 25590 | * | 1058 |
| 23 | 25950 | * | 1008 | 25900 | * | 1031 | 26690 | * | 1065 |
| 24 | 26900 | * | 1068 | 26870 | * | 979 | 27640 | * | 1252 |
| 25 | 28300 | 938 | 285 | 27790 | 970 | 287 | 28290 | 1346 | 202 |
| 26 | * | 542 | 628 | 28380 | 594 | 580 | * | 1141 | 321 |
| 27 | * | 594 | 638 | * | 504 | 390 | * | 896 | 400 |
| 28 | 30500 | 867 | 667 | * | 303 | 736 | 31030 | 929 | 467 |
| 29 | * | 684 | 591 | * | 718 | 460 | * | 852 | 543 |
| 30 | * | 902 | 493 | 31040 | 751 | 436 | * | 985 | 536 |
| 31 | 32540 | 778 | 524 | * | 580 | 710 | 33460 | 894 | 597 |
| 32 | * | 1139 | 335 | * | 597 | 522 | * | 1004 | 432 |
| 33 | * | 1045 | 425 | 33620 | 749 | 599 | * | 955 | 510 |
| 34 | * | 848 | 380 | * | 897 | 327 | * | 853 | 691 |
| 35 | 36270 | 867 | 540 | * | 934 | 302 | 36880 | | |
| 36 | * | 917 | 507 | * | 954 | 376 | | | |
| 37 | 37610 | | | 36170 | | | | | |

| ROW | 19F LWT | 19FI L | 19FI H | 11M LWT | 11FI L | 11FI H | 14M LWT | 14FI L | 14FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11960 | 125 | * | 12050 | * | 622 | 12340 | * | 703 |
| 2 | 11360 | 566 | * | 12850 | * | 773 | 13090 | * | 660 |
| 3 | 12020 | 630 | * | 13680 | * | 821 | 13690 | * | 745 |
| 4 | 12490 | 490 | * | 14660 | * | 837 | 14210 | * | 798 |
| 5 | 12700 | 459 | * | 15440 | * | 841 | 15150 | * | 789 |
| 6 | 12560 | 608 | * | 16120 | * | 844 | 15960 | * | 780 |
| 7 | 13330 | 147 | 626 | 17040 | 271 | 505 | 16520 | 142 | 745 |
| 8 | 14400 | 35 | 736 | 17500 | 204 | 627 | 17300 | 16 | 769 |
| 9 | 14910 | 28 | 779 | 18010 | 48 | 777 | 17930 | 31 | 826 |
| 10 | 15640 | 17 | 759 | 18840 | 44 | 849 | 18760 | 234 | 528 |
| 11 | 16250 | 2 | 714 | 19560 | 28 | 856 | 19400 | 633 | 311 |
| 12 | 17260 | 290 | 449 | 20220 | 44 | 776 | 20000 | 509 | 347 |
| 13 | 17560 | 131 | 562 | 20880 | 71 | 626 | 20300 | 514 | 164 |
| 14 | 18180 | 221 | 498 | 21310 | 293 | 592 | 20660 | 713 | 308 |
| 15 | 18790 | 276 | 491 | 22100 | 672 | 242 | 21510 | 418 | 570 |
| 16 | 19470 | 203 | 399 | 22530 | 685 | 345 | 22240 | 644 | 435 |
| 17 | 19870 | 133 | 608 | 23250 | 636 | 290 | 23000 | 617 | 543 |
| 18 | 20730 | 286 | 574 | 23850 | 450 | 398 | 23530 | 600 | 430 |
| 19 | 21390 | * | 835 | 24240 | 1054 | * | 24560 | 1179 | * |
| 20 | 21890 | * | 882 | 25100 | 30 | * | 25070 | 1368 | * |
| 21 | 22770 | * | 771 | 24140 | 1022 | * | 25830 | 1188 | * |
| 22 | 23600 | * | 892 | 24700 | 272 | * | 26280 | 1386 | * |
| 23 | 24240 | * | 983 | 24080 | 779 | * | 27030 | 1399 | * |
| 24 | 24840 | * | 1076 | 24120 | 1011 | * | 27670 | 1296 | * |
| 25 | 25710 | 954 | 462 | 25570 | 1016 | 929 | 28490 | 247 | 990 |
| 26 | * | 1042 | 267 | 27910 | 641 | 680 | * | 362 | 892 |
| 27 | 27250 | 930 | 300 | * | 687 | 609 | * | 662 | 652 |
| 28 | * | 811 | 524 | * | 411 | 595 | 31200 | 665 | 462 |
| 29 | * | 1008 | 480 | * | 747 | 472 | * | 877 | 592 |
| 30 | 29250 | 801 | 438 | 31070 | 680 | 565 | * | 966 | 331 |
| 31 | * | 826 | 495 | * | 769 | 630 | * | 944 | 522 |
| 32 | * | 696 | 406 | * | 604 | 576 | 34260 | 1095 | 114 |
| 33 | * | 707 | 542 | 33520 | 1081 | 446 | * | 1105 | 351 |
| 34 | 32490 | 850 | 496 | * | 1144 | 167 | * | 1418 | 386 |
| 35 | * | 691 | 547 | * | 1135 | 104 | 36540 | 1247 | 255 |
| 36 | * | 666 | 317 | * | 1288 | 75 | * | 958 | 463 |
| 37 | 34560 | | | 33620 | | | 38610 | | |

| ROW | 36F LWT | 36FI L | 36FI H | 24F LWT | 24FI L | 24FI H | 35M LWT | 35FI L | 35FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11790 | * | 657 | 12400 | * | 594 | 12290 | 18 | 661 |
| 2 | 12270 | * | 722 | 12850 | * | 750 | 13190 | 86 | 510 |
| 3 | 12910 | * | 836 | 13420 | * | 932 | 13560 | 4 | 655 |
| 4 | 13540 | * | 750 | 14390 | * | 743 | 14220 | 152 | 395 |
| 5 | 14070 | * | 816 | 15000 | * | 779 | 14780 | 16 | 640 |
| 6 | 14680 | * | 743 | 15520 | * | 826 | 15120 | 40 | 756 |
| 7 | 15180 | 944 | 12 | 16300 | 605 | 259 | 16090 | 24 | 832 |
| 8 | 15810 | 856 | 3 | 16920 | 377 | 407 | 16950 | 208 | 729 |
| 9 | 16290 | 879 | 15 | 17440 | 287 | 175 | 18060 | 10 | 899 |
| 10 | 16510 | 766 | 36 | 17620 | 368 | 564 | 18380 | 100 | 766 |
| 11 | 17000 | 774 | 58 | 18700 | 403 | 758 | 19130 | 21 | 933 |
| 12 | 17500 | 870 | 5 | 19610 | 224 | 794 | 20260 | 281 | 775 |
| 13 | 18040 | 852 | 100 | 20210 | 792 | 258 | 21120 | 205 | 716 |
| 14 | 18190 | 767 | 99 | 20990 | 659 | 521 | 21880 | 220 | 720 |
| 15 | 19160 | 743 | 187 | 21690 | 706 | 378 | 22490 | 561 | 515 |
| 16 | 19680 | 689 | 310 | 22430 | 359 | 368 | 23540 | 541 | 388 |
| 17 | 20380 | 344 | 428 | 22660 | 473 | 281 | 24060 | 166 | 804 |
| 18 | 20640 | 491 | 660 | 23180 | 234 | 783 | 24760 | 692 | 361 |
| 19 | 21780 | 1080 | * | 24160 | 1004 | * | 25390 | 837 | 244 |
| 20 | 22350 | 982 | * | 24890 | 1238 | * | 25900 | 905 | 197 |
| 21 | 22960 | 814 | * | 25280 | 1220 | * | 26730 | 526 | 629 |
| 22 | 23130 | 1155 | * | 26100 | 1309 | * | 27130 | 619 | 463 |
| 23 | 23720 | 1054 | * | 26680 | 1393 | * | 28140 | 376 | 626 |
| 24 | 24280 | 1186 | * | 27400 | 1492 | * | 28190 | 541 | 808 |
| 25 | 24920 | 17 | 956 | 27870 | 163 | 1371 | 29790 | 617 | 576 |
| 26 | * | 393 | 756 | * | 366 | 1208 | * | 517 | 660 |
| 27 | * | 437 | 617 | * | 837 | 794 | * | 510 | 686 |
| 28 | 27110 | 382 | 791 | 30980 | 752 | 716 | 32610 | 845 | 526 |
| 29 | * | 633 | 414 | * | 1262 | 334 | * | 928 | 718 |
| 30 | * | 430 | 743 | * | 1275 | 349 | * | 749 | 639 |
| 31 | 29840 | 808 | 580 | * | 1260 | 391 | 35620 | 547 | 938 |
| 32 | * | 571 | 549 | 34710 | 1267 | 541 | * | 781 | 937 |
| 33 | * | 537 | 753 | * | 1258 | 558 | * | 754 | 910 |
| 34 | 30990 | | | * | 1246 | 516 | * | 516 | 714 |
| 35 | | | | 38010 | 1202 | 658 | 38640 | | |
| 36 | | | | * | 1085 | 457 | | | |
| 37 | | | | 39080 | | | | | |

| ROW | 29M LWT | 29FI L | 29FI H | 5M LWT | 5FI L | 5FI H | 16F LWT | 16FI L | 16FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11820 | 88 | 343 | 12330 | 7 | 808 | 12460 | 3 | 764 |
| 2 | 12080 | 32 | 531 | 13090 | 49 | 729 | 13230 | 5 | 843 |
| 3 | 12660 | 44 | 667 | 14290 | 4 | 761 | 13920 | 2 | 861 |
| 4 | 13430 | 14 | 812 | 15010 | 23 | 822 | 14620 | 0 | 792 |
| 5 | 14350 | 338 | 539 | 15700 | 93 | 772 | 15500 | 504 | 632 |
| 6 | 14900 | 12 | 816 | 16280 | 951 | 5 | 16130 | 347 | 592 |
| 7 | 16020 | 370 | 613 | 17110 | 870 | 3 | 17280 | 606 | 493 |
| 8 | 16640 | 259 | 269 | 17460 | 872 | 51 | 17730 | 518 | 560 |
| 9 | 17120 | 637 | 274 | 17570 | 967 | 70 | 18460 | 380 | 444 |
| 10 | 17650 | 695 | 106 | 18060 | 855 | 279 | 19030 | 629 | 537 |
| 11 | 18030 | 698 | 229 | 18930 | 691 | 367 | 20020 | 573 | 313 |
| 12 | 18700 | 75 | 874 | 19530 | 626 | 313 | 20500 | 609 | 308 |
| 13 | 19430 | 673 | 354 | 20260 | 550 | 291 | 20870 | 520 | 396 |
| 14 | 20150 | 671 | 346 | 20460 | 383 | 503 | 21450 | 348 | 391 |
| 15 | 20680 | 243 | 658 | 21200 | 381 | 575 | 21950 | 342 | 562 |
| 16 | 21660 | 634 | 477 | 22080 | 625 | 537 | 22720 | 285 | 286 |
| 17 | 22630 | 614 | 310 | 22980 | 691 | 345 | 22730 | 499 | 505 |
| 18 | 23120 | 332 | 546 | 23430 | 540 | 427 | 23750 | 319 | 557 |
| 19 | 23770 | 507 | 380 | 24030 | 720 | 385 | 24480 | 447 | 384 |
| 20 | 24170 | 548 | 447 | 24840 | 812 | 394 | 24590 | 477 | 559 |
| 21 | 24760 | 479 | 363 | 25300 | 876 | 336 | 25770 | 552 | 604 |
| 22 | 24880 | 540 | 391 | 26290 | 650 | 667 | 26710 | 755 | 550 |
| 23 | 25950 | 266 | 486 | 27440 | 788 | 463 | 27430 | 529 | 568 |
| 24 | 26260 | 275 | 501 | 28190 | 933 | 311 | 28060 | 538 | 766 |
| 25 | 26600 | 292 | 535 | 28850 | 716 | 319 | 29170 | 563 | 736 |
| 26 | * | 335 | 792 | * | 811 | 419 | * | 630 | 787 |
| 27 | * | 471 | 504 | * | 989 | 504 | 31050 | 664 | 882 |
| 28 | 29080 | 339 | 735 | 31180 | 1000 | 431 | * | 660 | 718 |
| 29 | * | 362 | 860 | * | 1175 | 361 | * | 536 | 866 |
| 30 | * | 281 | 666 | * | 1372 | 234 | 33730 | 406 | 494 |
| 31 | * | 436 | 720 | 33390 | 1437 | 217 | * | 631 | 768 |
| 32 | 32970 | 391 | 803 | * | 989 | 182 | * | 827 | 802 |
| 33 | * | 185 | 930 | * | 1061 | 243 | * | 944 | 682 |
| 34 | * | 266 | 909 | * | 1344 | 374 | 36850 | 1019 | 765 |
| 35 | 35130 | 696 | 685 | 36550 | 1559 | 123 | * | 1120 | 647 |
| 36 | * | 417 | 892 | * | 1357 | 180 | * | 1175 | 505 |
| 37 | 37020 | | | 37640 | | | 39790 | | |

| ROW | 9F LWT | 9FI L | 9FI H | 11F LWT | 11aFI L | 11aFI H | 4M LWT | 4FI L | 4FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11960 | 202 | 251 | 11910 | 613 | 43 | 11880 | * | 875 |
| 2 | 12090 | 117 | 462 | 12150 | 768 | 4 | 13280 | 755 | * |
| 3 | 12830 | 189 | 552 | 12840 | 704 | 74 | 13700 | * | 674 |
| 4 | 13450 | 303 | 586 | 13320 | 752 | 54 | 14150 | 656 | * |
| 5 | 14250 | 328 | 502 | 13780 | 810 | 55 | 14480 | * | 636 |
| 6 | 14950 | 388 | 553 | 14430 | 839 | 84 | 15190 | 843 | * |
| 7 | 15550 | 440 | 470 | 14910 | 926 | 87 | 15510 | * | 702 |
| 8 | 16230 | 367 | 612 | 15220 | 947 | 54 | 16110 | 827 | * |
| 9 | 16810 | 338 | 543 | 15720 | 1078 | 65 | 16600 | * | 736 |
| 10 | 17630 | 385 | 498 | 16640 | 938 | 66 | 17260 | 798 | * |
| 11 | 18110 | 216 | 686 | 17130 | 914 | 160 | 17500 | * | 724 |
| 12 | 19070 | 535 | 435 | 17770 | 1020 | 122 | 18210 | 956 | * |
| 13 | 19780 | 459 | 450 | 18360 | 1118 | 92 | 18750 | * | 784 |
| 14 | 20280 | 788 | 285 | 19240 | 1082 | 176 | 19700 | 874 | * |
| 15 | 21090 | 663 | 351 | 19790 | 1060 | 190 | 20110 | * | 730 |
| 16 | 21840 | 626 | 397 | 20470 | 1096 | 135 | 21030 | 1048 | * |
| 17 | 22010 | 678 | 374 | 21140 | 1056 | 245 | 21340 | * | 905 |
| 18 | 22870 | 639 | 374 | 21840 | 1093 | 109 | 22290 | 1078 | * |
| 19 | 23590 | 753 | 339 | 22310 | 942 | 156 | 22750 | * | 898 |
| 20 | 24090 | 637 | 594 | 23110 | 948 | 96 | 23910 | 1083 | * |
| 21 | 24900 | 750 | 316 | 23620 | 1024 | 175 | 24180 | * | 945 |
| 22 | 25780 | 630 | 560 | 24210 | 1047 | 214 | 24980 | 1291 | * |
| 23 | 26760 | 722 | 599 | 25140 | 925 | 254 | 25310 | * | 1135 |
| 24 | 27860 | 706 | 483 | 25700 | 910 | 250 | 26490 | 1328 | * |
| 25 | 28780 | 862 | 391 | 26420 | 879 | 224 | 27030 | * | 866 |
| 26 | 29310 | 886 | 531 | * | 923 | 343 | * | 1320 | * |
| 27 | * | 1053 | 298 | 27930 | 781 | 227 | 28520 | * | 843 |
| 28 | * | 873 | 345 | * | 1069 | 307 | * | 1297 | * |
| 29 | * | 820 | 500 | * | 867 | 322 | * | * | 851 |
| 30 | 32490 | 939 | 417 | * | 1026 | 204 | 30570 | 1338 | * |
| 31 | * | 897 | 277 | 30530 | 1013 | 250 | * | * | 904 |
| 32 | * | 660 | 259 | * | 1058 | 264 | * | 1431 | * |
| 33 | 34270 | 533 | 425 | * | 1051 | 274 | * | * | 823 |
| 34 | * | 780 | 653 | 32520 | 1078 | 351 | 33260 | 1351 | * |
| 35 | * | 731 | 784 | * | 966 | 271 | * | * | 766 |
| 36 | * | 965 | 749 | * | 1097 | 174 | * | 1470 | * |
| 37 | 38320 | | | 34640 | | | 35900 | | |

| ROW | 40M LWT | 40FI L | 40FI H | 13F LWT | 13FI L | 13FI H | 6F LWT | 6FI L | 6FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12030 | * | 495 | 12250 | * | 748 | 11970 | 328 | * |
| 2 | 13000 | 568 | * | 13070 | 762 | * | 12170 | * | 446 |
| 3 | 13250 | * | 790 | 13300 | * | 838 | 12660 | 785 | * |
| 4 | 14200 | 823 | * | 14180 | 935 | * | 13470 | * | 710 |
| 5 | 14730 | * | 605 | 14680 | * | 982 | 13820 | 884 | * |
| 6 | 14910 | 698 | * | 15450 | 954 | * | 14630 | * | 815 |
| 7 | 15590 | * | 935 | 16030 | * | 927 | 15130 | 994 | * |
| 8 | 16420 | 781 | * | 16750 | 1162 | * | 15730 | * | 731 |
| 9 | 17270 | * | 991 | 17530 | * | 1054 | 16130 | 1003 | * |
| 10 | 17820 | 927 | * | 18600 | 796 | * | 16820 | * | 634 |
| 11 | 18870 | * | 1010 | 18770 | * | 849 | 17330 | 970 | * |
| 12 | 19630 | 951 | * | 19310 | 913 | * | 18030 | * | 645 |
| 13 | 20570 | * | 851 | 19930 | * | 663 | 18510 | 1055 | * |
| 14 | 20830 | 905 | * | 20460 | 934 | * | 19160 | * | 924 |
| 15 | 21450 | * | 1052 | 21150 | * | 980 | 19910 | 1081 | * |
| 16 | 22550 | 966 | * | 21860 | 1116 | * | 20340 | * | 860 |
| 17 | 22750 | * | 1186 | 21870 | * | 1339 | 21090 | 1177 | * |
| 18 | 23940 | 1194 | * | 23460 | 1422 | * | 21860 | * | 1050 |
| 19 | 25170 | * | 1290 | 24360 | * | 1352 | 22570 | 1181 | * |
| 20 | 26200 | 1343 | * | 25290 | 1517 | * | 23090 | * | 1080 |
| 21 | 26350 | * | 1453 | 26090 | * | 956 | 24040 | 1277 | * |
| 22 | 27880 | 1454 | * | 26720 | 1142 | * | 24900 | * | 947 |
| 23 | 28360 | * | 1509 | 27600 | * | 1082 | 25750 | 1166 | * |
| 24 | 29600 | 1289 | * | 28490 | 1366 | * | 26020 | * | 829 |
| 25 | 30480 | * | 1350 | 28590 | * | 1241 | 26820 | 1132 | * |
| 26 | * | 1233 | * | * | 1326 | * | * | * | 1181 |
| 27 | * | * | 1281 | 30410 | * | 1357 | 28310 | 1223 | * |
| 28 | 33520 | 1294 | * | * | 1523 | * | * | * | 1108 |
| 29 | * | * | 1204 | * | * | 1332 | * | 1469 | * |
| 30 | * | 1119 | * | 33330 | 1478 | * | 30630 | * | 1313 |
| 31 | * | * | 1339 | * | * | 1242 | * | 1576 | * |
| 32 | 36920 | 1375 | * | * | 1260 | * | * | * | 1213 |
| 33 | * | * | 1459 | * | * | 1248 | * | 1577 | * |
| 34 | * | 1562 | * | 36020 | | | 34060 | * | 1236 |
| 35 | 38680 | * | 1565 | | | | * | 1725 | * |
| 36 | * | 1599 | * | | | | * | * | 1076 |
| 37 | 40380 | | | | | | 36030 | | |

| ROW | 34M LWT | 34FI L | 21M LWT | 21FI L | 10F LWT | 10FI L | 37M LWT | 37FI A |
|---|---|---|---|---|---|---|---|---|
| 1 | 12200 | 724 | 11730 | 529 | 11780 | 672 | 12220 | 762 |
| 2 | 12740 | 801 | 12140 | 751 | 12410 | 764 | 13120 | 693 |
| 3 | 13540 | 708 | 12550 | 777 | 12690 | 866 | 13470 | 767 |
| 4 | 14020 | 835 | 13000 | 546 | 13010 | 1071 | 14070 | 765 |
| 5 | 14270 | 824 | 13090 | 688 | 14060 | 1193 | 14740 | 744 |
| 6 | 14650 | 911 | 13450 | 851 | 14470 | 1284 | 14910 | 727 |
| 7 | 15140 | 854 | 14070 | 937 | 15340 | 1155 | 15400 | 705 |
| 8 | 15430 | 796 | 14760 | 1001 | 15810 | 1275 | 16010 | 878 |
| 9 | 15620 | 894 | 15220 | 881 | 16820 | 1257 | 16420 | 837 |
| 10 | 16330 | 921 | 15700 | 794 | 17260 | 1327 | 16940 | 942 |
| 11 | 16530 | 978 | 16270 | 672 | 17900 | 967 | 17710 | 893 |
| 12 | 17130 | 982 | 16370 | 759 | 18010 | 976 | 18570 | 914 |
| 13 | 17730 | 1046 | 16810 | 937 | 18470 | 1171 | 19000 | 831 |
| 14 | 18110 | 914 | 17350 | 950 | 19180 | 1191 | 19230 | 900 |
| 15 | 18420 | 970 | 17890 | 988 | 19830 | 1206 | 19910 | 750 |
| 16 | 19020 | 1092 | 18520 | 898 | 20370 | 1260 | 20270 | 809 |
| 17 | 19400 | 896 | 19020 | 941 | 21270 | 1306 | 20610 | 936 |
| 18 | 19330 | 1090 | 19430 | 954 | 21990 | 1310 | 21450 | 978 |
| 19 | 20150 | 1136 | 19830 | 1063 | 22460 | 1353 | 21980 | 866 |
| 20 | 20580 | 1217 | 20530 | 1147 | 23120 | 1430 | 22570 | 892 |
| 21 | 21410 | 1213 | 21400 | 1265 | 23970 | 1342 | 23190 | 891 |
| 22 | 21590 | 1348 | 22040 | 1337 | 24510 | 1178 | 23560 | 906 |
| 23 | 22400 | 1283 | 23010 | 1406 | 24910 | 1315 | 24290 | 1010 |
| 24 | 22870 | 1313 | 23230 | 1268 | 25920 | 1343 | 24920 | 944 |
| 25 | 23500 | 1141 | 23790 | 1313 | 26660 | 1419 | 25790 | 988 |
| 26 | * | 1348 | * | 1204 | 27360 | 1327 | * | 970 |
| 27 | * | 1424 | * | 1284 | * | 1376 | * | 982 |
| 28 | 25150 | 1435 | 25730 | 1219 | * | 1371 | * | 1016 |
| 29 | * | 1407 | * | 1282 | * | 1186 | 28090 | 874 |
| 30 | * | 1325 | * | 1290 | 29630 | 1092 | * | 936 |
| 31 | * | 1222 | 27740 | 1383 | * | 1052 | * | 1014 |
| 32 | 27370 | 1398 | * | 1491 | * | 1296 | 30030 | 991 |
| 33 | * | 1215 | * | 1491 | 31040 | 1344 | * | 1173 |
| 34 | * | 1177 | * | 1424 | * | 1323 | * | 972 |
| 35 | 28890 | 1065 | 30470 | 1395 | * | 1433 | * | 1090 |
| 36 | * | 1354 | * | 1445 | 33180 | 1346 | 32180 | |
| 37 | 29890 | | 30540 | | | | | |

| ROW | 31M LWT | 31FI A | 8F LWT | 8FI A | 25F LWT | 25FI A | 26M LWT | 26FI B |
|---|---|---|---|---|---|---|---|---|
| 1 | 11920 | 731 | 12020 | 689 | 12330 | 612 | 12000 | 569 |
| 2 | 12490 | 569 | 12510 | 697 | 12800 | 445 | 12130 | 735 |
| 3 | 12600 | 770 | 13210 | 795 | 12780 | 744 | 12760 | 843 |
| 4 | 13090 | 888 | 13610 | 787 | 13580 | 884 | 13480 | 916 |
| 5 | 13920 | 1019 | 14110 | 806 | 14130 | 859 | 14430 | 994 |
| 6 | 14840 | 1078 | 14600 | 918 | 14570 | 772 | 15180 | 927 |
| 7 | 15500 | 1011 | 15220 | 1025 | 15210 | 891 | 16050 | 1052 |
| 8 | 15900 | 1138 | 16010 | 1100 | 15710 | 1022 | 16960 | 987 |
| 9 | 16910 | 1217 | 16850 | 957 | 16740 | 1167 | 17620 | 935 |
| 10 | 17510 | 1255 | 17490 | 950 | 17380 | 1269 | 18290 | 844 |
| 11 | 18340 | 1287 | 17900 | 1104 | 18310 | 1214 | 18740 | 963 |
| 12 | 19200 | 1244 | 18480 | 1158 | 18940 | 1286 | 19740 | 1021 |
| 13 | 19970 | 1139 | 19290 | 1157 | 19980 | 1063 | 20540 | 1130 |
| 14 | 20640 | 1185 | 20070 | 978 | 20560 | 955 | 21590 | 551 |
| 15 | 21530 | 1007 | 20350 | 1078 | 21080 | 909 | 21610 | 938 |
| 16 | 21950 | 1222 | 20950 | 1060 | 21550 | 1188 | 22300 | 900 |
| 17 | 22620 | 1214 | 21570 | 1073 | 22410 | 1260 | 23050 | 1046 |
| 18 | 23460 | 1278 | 22220 | 1153 | 23180 | 1382 | 23990 | 1237 |
| 19 | 24440 | 1193 | 22910 | 1147 | 24500 | 1478 | 24750 | 1169 |
| 20 | 25200 | 1291 | 23850 | 905 | 25290 | 1477 | 25850 | 798 |
| 21 | 25950 | 1046 | 24130 | 1108 | 26360 | 1574 | 26190 | 1068 |
| 22 | 26440 | 1056 | 24740 | 1187 | 27240 | 1572 | 26860 | 1192 |
| 23 | 26940 | 1199 | 25840 | 1303 | 28140 | 1652 | 27690 | 1269 |
| 24 | 27550 | 1183 | 26120 | 1229 | 28930 | 1541 | 28390 | 1372 |
| 25 | 28410 | 1223 | 27120 | 1130 | 29780 | 1643 | 29240 | 1425 |
| 26 | 29410 | 1248 | * | 1070 | * | 1779 | 30270 | 1380 |
| 27 | * | 1363 | 28330 | 1277 | 31900 | 1846 | * | 1409 |
| 28 | * | 1405 | * | 1300 | * | 1843 | * | 1383 |
| 29 | 31640 | 1239 | * | 1446 | * | 1166 | * | 1387 |
| 30 | * | 1399 | * | 1562 | * | 1383 | 33160 | 1358 |
| 31 | * | 1526 | 31680 | 1883 | 35150 | 1576 | * | 1482 |
| 32 | * | 1430 | * | 1853 | * | 1678 | * | 1300 |
| 33 | 35210 | 1518 | * | 1719 | * | 1854 | 35950 | 1343 |
| 34 | * | 1365 | 34770 | 1448 | 38130 | 1827 | * | 1541 |
| 35 | * | 1432 | * | 1446 | * | 1784 | * | 1566 |
| 36 | 37480 | 1396 | * | 1201 | * | 1544 | * | 1332 |
| 37 | 38070 | | 37140 | | 41120 | | 39070 | |

| ROW | 7M LWT | 7FI B | 2F LWT | 2FI B | 19aF LWT | 19FI B | 17M LWT | 17FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 12360 | 575 | 12210 | 528 | 12010 | 596 | 11880 | 656 |
| 2 | 12620 | 664 | 12570 | 567 | 12830 | 736 | 12830 | 700 |
| 3 | 13150 | 839 | 12700 | 771 | 13040 | 764 | 13410 | 522 |
| 4 | 13950 | 794 | 14000 | 794 | 13730 | 796 | 13680 | 680 |
| 5 | 14910 | 864 | 14520 | 736 | 14530 | 900 | 14410 | 791 |
| 6 | 16030 | 928 | 14830 | 805 | 15180 | 1050 | 15410 | 781 |
| 7 | 16350 | 1059 | 15730 | 472 | 16020 | 986 | 16200 | 883 |
| 8 | 17360 | 1049 | 15920 | 891 | 16940 | 1076 | 16910 | 991 |
| 9 | 18120 | 981 | 16950 | 906 | 17710 | 993 | 18130 | 1070 |
| 10 | 18950 | 888 | 17710 | 812 | 18570 | 1008 | 18970 | 859 |
| 11 | 19550 | 914 | 18000 | 872 | 19070 | 1272 | 19510 | 821 |
| 12 | 20250 | 937 | 19000 | 964 | 20350 | 1337 | 20230 | 967 |
| 13 | 20910 | 949 | 19770 | 933 | 21220 | 1248 | 20920 | 825 |
| 14 | 21540 | 1052 | 20650 | 1030 | 21730 | 1192 | 21590 | 712 |
| 15 | 22390 | 1016 | 21650 | 1077 | 22910 | 1198 | 22090 | 912 |
| 16 | 22790 | 1061 | 22230 | 1089 | 23390 | 1236 | 22970 | 1034 |
| 17 | 23890 | 1112 | 23290 | 1066 | 23880 | 952 | 23530 | 1148 |
| 18 | 24590 | 1172 | 23960 | 1039 | 24680 | | 24450 | 1024 |
| 19 | 25450 | 1096 | 24550 | 1270 | | | 25070 | 1072 |
| 20 | 26480 | 1164 | 26070 | 1233 | | | 25970 | 1137 |
| 21 | 27210 | 1327 | 26680 | 1313 | | | 26710 | 1228 |
| 22 | 28290 | 1187 | 27640 | 1335 | | | 27520 | 1126 |
| 23 | 28900 | 1140 | 28480 | 1380 | | | 28080 | 1322 |
| 24 | 29820 | 1284 | 29580 | 1398 | | | 29360 | 1258 |
| 25 | 30800 | 1210 | 30350 | 1348 | | | 30320 | 1205 |
| 26 | 31800 | 1023 | * | 1214 | | | * | 1380 |
| 27 | * | 1222 | 31810 | 1321 | | | * | 1360 |
| 28 | * | 1295 | * | 1248 | | | 32950 | 1407 |
| 29 | 33950 | 1157 | * | 1482 | | | * | 1458 |
| 30 | * | 1256 | * | 1590 | | | * | 1422 |
| 31 | * | 1334 | 35970 | 1610 | | | * | 1367 |
| 32 | * | 1466 | * | 1772 | | | 35930 | 1529 |
| 33 | 37260 | 1654 | * | 1692 | | | * | 1453 |
| 34 | * | 1774 | 38310 | 1240 | | | * | 1310 |
| 35 | * | 1715 | * | 1276 | | | 38840 | 1394 |
| 36 | 40870 | 1358 | 40170 | 1415 | | | * | 1538 |
| 37 | 41560 | | | | | | 40270 | |

| ROW | 38M LWT | 38FI H | 28F LWT | 28FI H | 30F LWT | 30FI H |
|---|---|---|---|---|---|---|
| 1 | 11960 | 554 | 11970 | 600 | 12480 | 459 |
| 2 | 12610 | 733 | 12570 | 714 | 12820 | 599 |
| 3 | 13390 | 828 | 13460 | 516 | 13340 | 704 |
| 4 | 14450 | 804 | 13910 | 822 | 14340 | 847 |
| 5 | 15450 | 943 | 15050 | 711 | 15190 | 799 |
| 6 | 16160 | 966 | 15660 | 878 | 15700 | 690 |
| 7 | 17320 | 890 | 16520 | 923 | 16260 | 733 |
| 8 | 18110 | 688 | 17400 | 933 | 16710 | 804 |
| 9 | 17790 | 675 | 18430 | 971 | 17510 | 901 |
| 10 | 18430 | 864 | 19110 | 964 | 18310 | 1032 |
| 11 | 19350 | 963 | 20260 | 1006 | 19300 | 940 |
| 12 | 20640 | 1115 | 20860 | 977 | 20170 | 1061 |
| 13 | 21700 | 1150 | 22160 | 882 | 20490 | 1060 |
| 14 | 22900 | 1114 | 22180 | 1026 | 21500 | 705 |
| 15 | 24020 | 1211 | 23210 | 843 | 21590 | 1074 |
| 16 | 24870 | 974 | 23780 | 1022 | 22420 | 1025 |
| 17 | 25520 | 648 | 24960 | 719 | 23410 | 899 |
| 18 | 24910 | 1008 | 25460 | 1009 | 23690 | 1050 |
| 19 | 26560 | 1149 | 26020 | 970 | 24190 | 1091 |
| 20 | 27370 | 1188 | 26930 | 1154 | 25200 | 1159 |
| 21 | 28400 | 1222 | 27930 | 984 | 25360 | 1237 |
| 22 | 29340 | 1226 | 28390 | 1164 | 27030 | 1051 |
| 23 | 30540 | 1272 | 29390 | 1261 | 27090 | 1160 |
| 24 | 31170 | 1175 | 30390 | 1288 | 28300 | 1332 |
| 25 | 32400 | 1294 | * | 1364 | 29010 | 991 |
| 26 | * | 1307 | * | 1345 | 29360 | 1088 |
| 27 | * | 1363 | 32760 | 1463 | * | 1222 |
| 28 | * | 1397 | * | 1498 | * | 1127 |
| 29 | 36320 | 1437 | * | 1553 | 31870 | 1145 |
| 30 | * | 1426 | 35410 | 1658 | * | 1245 |
| 31 | * | 1516 | * | 1659 | * | 1276 |
| 32 | 38850 | 1523 | * | 1544 | * | 1215 |
| 33 | * | 1511 | * | 1554 | 34410 | 1271 |
| 34 | * | 1578 | 39220 | 1544 | * | 1195 |
| 35 | * | 1421 | * | 1380 | * | 1134 |
| 36 | 42410 | | * | 1385 | 36560 | 1147 |
| 37 | | | 40680 | | | |

## D. Liveweight and Feed Intake Data - Experiment 4

1-40 = Pig Identity; M or F = Sex; LWT = Liveweight (g); FI = Feed Intake (g); L, A, B or H = Feed.

| ROW | 16M LWT | 16FI L | 16FI A | 31M LWT | 31FI L | 31FI A | 23F LWT | 23FI L | 23FI A |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11980 | * | 550 | 11860 | 489 | * | 11930 | * | 504 |
| 2 | 12450 | 744 | * | 12280 | * | 612 | 12380 | 720 | * |
| 3 | 12980 | * | 799 | 12430 | 810 | * | 12900 | * | 648 |
| 4 | 13390 | 778 | * | 13200 | * | 456 | 13270 | 674 | * |
| 5 | 13410 | * | 840 | 13180 | 747 | * | 1390 | * | 797 |
| 6 | 14070 | 816 | * | 13720 | * | 620 | 14330 | 823 | * |
| 7 | 14470 | 11 | 814 | 14120 | 863 | 59 | 14760 | 2 | 725 |
| 8 | 15050 | 100 | 882 | 14880 | 992 | 23 | 15350 | 1 | 862 |
| 9 | 15760 | 113 | 984 | 15410 | 1053 | 33 | 15630 | 3 | 838 |
| 10 | 16320 | 12 | 838 | 16220 | 1163 | 22 | 16440 | 5 | 819 |
| 11 | 16880 | 4 | 1609 | 16800 | 1240 | 73 | 17220 | 0 | 974 |
| 12 | 17410 | 2 | 1083 | 17560 | 1287 | 33 | 17990 | 0 | 1136 |
| 13 | 18500 | 21 | 1040 | 18630 | 1243 | 30 | 18710 | 0 | 980 |
| 14 | 19050 | 6 | 1048 | 19120 | 1248 | 44 | 19380 | 14 | 1101 |
| 15 | 19870 | 36 | 1115 | 19870 | 1117 | 29 | 20010 | 8 | 1048 |
| 16 | 20440 | 3 | 1187 | 20340 | 1098 | 42 | 20800 | 5 | 1205 |
| 17 | 21180 | 123 | 1006 | 21030 | 847 | 8 | 21490 | 1 | 1156 |
| 18 | 21920 | 25 | 1009 | 21080 | 611 | 8 | 22590 | 0 | 1279 |
| 19 | 22470 | 35 | 1073 | 21600 | 798 | 19 | 23330 | 0 | 1035 |
| 20 | 23120 | 38 | 1064 | 21920 | 806 | 57 | 23910 | 0 | 1322 |
| 21 | 23840 | 176 | 1094 | 22320 | 1045 | 32 | 25050 | 6 | 1316 |
| 22 | 24590 | 20 | 1165 | 23130 | 1056 | 50 | 25760 | 0 | 1139 |
| 23 | 25460 | 80 | 1107 | 23440 | 939 | 66 | 26450 | 0 | 1149 |
| 24 | 25970 | 63 | 1188 | 23440 | 990 | 50 | 26850 | 19 | 1368 |
| 25 | 26850 | 93 | 1146 | 24610 | 934 | 186 | 27800 | 20 | 1323 |
| 26 | 27560 | 90 | 1222 | 24600 | 912 | 243 | 28640 | 68 | 1266 |
| 27 | 28240 | 60 | 1289 | 25490 | 890 | 186 | 29520 | 19 | 1198 |
| 28 | 29100 | 38 | 1310 | 26200 | 923 | 444 | 30090 | 104 | 1215 |
| 29 | 30110 | 8 | 1382 | 27170 | 996 | 489 |  | 0 | 1214 |
| 30 |  | 66 | 1483 | 28180 | 874 | 592 |  | 21 | 1038 |
| 31 |  | 67 | 1522 | 29030 | 618 | 890 |  | 158 | 1177 |
| 32 |  | 57 | 1303 | 29840 | 739 | 659 |  | 264 | 1169 |
| 33 |  | 44 | 673 |  | 954 | 816 |  | 251 | 1235 |
| 34 |  | 2 | 1184 |  | 895 | 712 |  | 112 | 1293 |
| 35 |  | 247 | 983 |  | 696 | 721 |  |  |  |
| 36 |  |  |  |  | 981 | 517 |  |  |  |
| 37 |  |  |  |  | 517 | 677 |  |  |  |
| 38 |  |  |  |  | 86 | 819 |  |  |  |

| ROW | 18F LWT | 18FI L | 18FI A | 11M LWT | 11FI L | 11FI B | 1M LWT | 1FI L | 1FI B |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12130 | 531 | * | 12640 | 520 | * | 12420 | * | 688 |
| 2 | 11960 | * | 689 | 12740 | * | 531 | 12920 | 856 | * |
| 3 | 12920 | 638 | * | 13330 | 650 | * | 13260 | * | 754 |
| 4 | 12920 | * | 587 | 13670 | * | 670 | 13970 | 930 | * |
| 5 | 13420 | 662 | * | 14420 | 546 | * | 14420 | * | 812 |
| 6 | 13660 | * | 629 | 14540 | * | 681 | 15280 | 974 | * |
| 7 | 14080 | 203 | 783 | 15240 | 4 | 719 | 15480 | 11 | 1010 |
| 8 | 14910 | 196 | 794 | 15730 | 8 | 743 | 16470 | 4 | 1007 |
| 9 | 15470 | 159 | 629 | 16440 | 20 | 732 | 17280 | 1 | 972 |
| 10 | 16290 | 257 | 601 | 17160 | 17 | 802 | 18250 | 5 | 942 |
| 11 | 16560 | 215 | 736 | 17780 | 14 | 861 | 18750 | 3 | 965 |
| 12 | 17350 | 468 | 492 | 18700 | 11 | 865 | 19690 | 2 | 944 |
| 13 | 17720 | 439 | 620 | 19390 | 11 | 958 | 20330 | 0 | 946 |
| 14 | 18350 | 245 | 669 | 20360 | 6 | 899 | 21080 | 2 | 927 |
| 15 | 19230 | 271 | 844 | 21020 | 16 | 898 | 21740 | 5 | 1040 |
| 16 | 19870 | 327 | 770 | 21800 | 46 | 969 | 22840 | 10 | 968 |
| 17 | 20320 | 397 | 622 | 22500 | 22 | 1028 | 23460 | 8 | 981 |
| 18 | 20790 | 218 | 710 | 23500 | 91 | 874 | 24070 | 5 | 1195 |
| 19 | 21560 | 182 | 770 | 24250 | 32 | 986 | 24900 | 1 | 1117 |
| 20 | 22080 | 212 | 858 | 24810 | 19 | 894 | 25660 | 0 | 1130 |
| 21 | 22880 | 194 | 748 | 25810 | 262 | 747 | 26690 | 3 | 1095 |
| 22 | 23380 | 272 | 706 | 26140 | 164 | 730 | 27390 | 0 | 1147 |
| 23 | 24030 | 318 | 769 | 26910 | 154 | 770 | 27990 | 3 | 1115 |
| 24 | 24590 | 224 | 748 | 27580 | 196 | 838 | 29100 | 3 | 1051 |
| 25 | 25230 | 333 | 891 | 28400 | 277 | 803 | 29560 | 0 | 1074 |
| 26 | 25900 | 181 | 1005 | 29480 | 375 | 526 | 30140 | 43 | 1111 |
| 27 | 26600 | 152 | 999 | 29860 | 189 | 928 | | 0 | 1079 |
| 28 | 27420 | 178 | 1075 | | 351 | 780 | | 4 | 1150 |
| 29 | 27880 | 190 | 1229 | | 259 | 870 | | 73 | 1312 |
| 30 | 29100 | 125 | 1150 | | 171 | 1029 | | 116 | 1290 |
| 31 | 29880 | 253 | 931 | | 147 | 911 | | 196 | 1128 |
| 32 | | 353 | 1063 | | 118 | 1106 | | 249 | 1006 |
| 33 | | 498 | 841 | | 270 | 837 | | | |
| 34 | | 409 | 669 | | | | | | |
| 35 | | 354 | 1126 | | | | | | |
| 36 | | 236 | 1179 | | | | | | |
| 37 | | 75 | 1321 | | | | | | |

| ROW | 36F LWT | 36FI L | 36FI B | 28F LWT | 28FI L | 28FI B | 26M LWT | 26FI L | 26FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12030 | 404 | * | 11970 | * | 422 | 11970 | 420 | * |
| 2 | 11790 | * | 545 | 12100 | 736 | * | 12450 | * | 499 |
| 3 | 12360 | 294 | * | 12420 | * | 494 | 12510 | 547 | * |
| 4 | 12350 | * | 527 | 12530 | 679 | * | 12650 | * | 633 |
| 5 | 13000 | 607 | * | 12980 | * | 750 | 13430 | 713 | * |
| 6 | 13230 | * | 901 | 13570 | 1150 | * | 14010 | * | 520 |
| 7 | 14300 | 7 | 969 | 14290 | 0 | 1043 | 14490 | 228 | 478 |
| 8 | 15480 | 118 | 570 | 15220 | 0 | 970 | 15150 | 167 | 691 |
| 9 | 15710 | 76 | 812 | 16010 | 2 | 962 | 15990 | 291 | 697 |
| 10 | 16760 | 151 | 809 | 16390 | 0 | 803 | 17070 | 269 | 660 |
| 11 | 17480 | 25 | 837 | 17030 | 0 | 776 | 17900 | 57 | 637 |
| 12 | 18120 | 56 | 785 | 17750 | 0 | 594 | 18250 | 278 | 524 |
| 13 | 18820 | 34 | 914 | 18090 | 0 | 684 | 18780 | 299 | 559 |
| 14 | 19460 | 168 | 959 | 18390 | 0 | 835 | 19610 | 158 | 773 |
| 15 | 20690 | 118 | 846 | 19440 | 40 | 999 | 20520 | 384 | 745 |
| 16 | 20720 | 152 | 745 | 20440 | 15 | 1038 | 21280 | 257 | 736 |
| 17 | 21400 | 156 | 769 | 21340 | 0 | 962 | 22270 | 447 | 642 |
| 18 | 22550 | 287 | 729 | 21550 | 0 | 1044 | 22900 | 639 | 577 |
| 19 | 23290 | 248 | 914 | 22420 | 8 | 1000 | 23870 | 644 | 604 |
| 20 | 24010 | 280 | 801 | 23000 | 5 | 1185 | 24880 | 335 | 647 |
| 21 | 24830 | 189 | 905 | 23720 | 14 | 1145 | 25290 | 350 | 760 |
| 22 | 25390 | 162 | 1056 | 24150 | 20 | 1158 | 25690 | 765 | 572 |
| 23 | 26420 | 105 | 1170 | 24980 | 14 | 1157 | 27050 | 498 | 610 |
| 24 | 27470 | 240 | 1194 | 25630 | 0 | 1237 | 27510 | 505 | 616 |
| 25 | 28500 | 361 | 920 | 26500 | 8 | 1363 | 28730 | 806 | 604 |
| 26 | 29140 | 156 | 1140 | 27360 | 3 | 1290 | 29490 | 726 | 686 |
| 27 | 30460 | 261 | 1031 | 28060 | 0 | 1059 | 29820 | 736 | 689 |
| 28 | | 433 | 1206 | 28300 | 5 | 1443 | 30830 | 969 | 272 |
| 29 | | 336 | 1121 | 29720 | 90 | 1184 | | 872 | 609 |
| 30 | | 338 | 1213 | 30330 | 12 | 1249 | | 737 | 807 |
| 31 | | 360 | 1168 | | 13 | 1498 | | 1054 | 503 |
| 32 | | 347 | 1204 | | 0 | 1272 | | 816 | 664 |
| 33 | | 425 | 1033 | | 0 | 1378 | | 945 | 627 |
| 34 | | | | | 0 | 1341 | | 900 | 682 |
| 35 | | | | | 0 | 1186 | | | |
| 36 | | | | | 0 | 1253 | | | |

| ROW | 33M LWT | 33FI L | 33FI H | 15F LWT | 15FI L | 15FI H | 13F LWT | 13FI L | 13FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11900 | * | 494 | 11970 | 456 | * | 11870 | * | 678 |
| 2 | 12660 | 598 | * | 12430 | * | 612 | 12310 | 14 | * |
| 3 | 12990 | * | 680 | 13110 | 573 | * | 11290 | * | 953 |
| 4 | 13540 | 704 | * | 13430 | * | 695 | 13620 | 659 | * |
| 5 | 14160 | * | 566 | 14370 | 624 | * | 13480 | * | 972 |
| 6 | 14580 | 654 | * | 14670 | * | 740 | 14520 | 876 | * |
| 7 | 14870 | 73 | 659 | 15530 | 55 | 601 | 15000 | 70 | 920 |
| 8 | 15810 | 383 | 177 | 16320 | 100 | 687 | 15930 | 256 | 927 |
| 9 | 15710 | 29 | 441 | 16670 | 53 | 686 | 16820 | 395 | 678 |
| 10 | 15140 | 255 | 175 | 17410 | 187 | 641 | 17660 | 561 | 353 |
| 11 | 16000 | 19 | 673 | 18370 | 269 | 649 | 18060 | 534 | 486 |
| 12 | 17300 | 51 | 763 | 19120 | 424 | 624 | 18710 | 698 | 381 |
| 13 | 18290 | 172 | 553 | 20250 | 210 | 671 | 19640 | 755 | 501 |
| 14 | 18890 | 91 | 706 | 20750 | 335 | 716 | 20280 | 780 | 436 |
| 15 | 19650 | 103 | 898 | 21510 | 288 | 882 | 21150 | 768 | 458 |
| 16 | 20630 | 106 | 1010 | 22590 | 376 | 956 | 21580 | 908 | 246 |
| 17 | 21730 | 437 | 619 | 23780 | 459 | 569 | 22540 | 1048 | 370 |
| 18 | 22310 | 234 | 944 | 24500 | 596 | 576 | 23620 | 1047 | 306 |
| 19 | 23210 | 212 | 707 | 25400 | 354 | 726 | 24330 | 893 | 394 |
| 20 | 23730 | 272 | 662 | 26050 | 761 | 603 | 25130 | 750 | 438 |
| 21 | 24430 | 441 | 457 | 26670 | 691 | 534 | 25910 | 886 | 413 |
| 22 | 25130 | 588 | 425 | 27850 | 880 | 599 | 26640 | 930 | 365 |
| 23 | 25430 | 648 | 356 | 29050 | 594 | 658 | 27540 | 839 | 301 |
| 24 | 26300 | 777 | 347 | 29860 | 501 | 779 | 27870 | 772 | 374 |
| 25 | 27080 | 785 | 396 | 30600 | 443 | 832 | 28570 | 666 | 295 |
| 26 | 27860 | 803 | 337 | | 348 | 1029 | 29820 | 803 | 411 |
| 27 | 28130 | 797 | 421 | | 950 | 636 | | 584 | 523 |
| 28 | 29250 | 886 | 292 | | 887 | 813 | | 886 | 507 |
| 29 | 29780 | 521 | 650 | | 1136 | 635 | | 628 | 723 |
| 30 | | 769 | 827 | | 948 | 732 | | 587 | 849 |
| 31 | | 782 | 531 | | 979 | 706 | | 564 | 720 |
| 32 | | 1116 | 352 | | | | | 751 | 439 |
| 33 | | 1075 | 429 | | | | | | |
| 34 | | 1116 | 199 | | | | | | |
| 35 | | 1190 | 302 | | | | | | |

| ROW | 10M LWT | 10FI A | 10FI B | 8M LWT | 8FI A | 8FI B | 35F LWT | 35FI A | 35FI B |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12210 | 576 | * | 12000 | * | 423 | 12000 | 537 | * |
| 2 | 12300 | * | 584 | 12320 | 597 | * | 12410 | * | 351 |
| 3 | 13000 | 673 | * | 12450 | * | 678 | 12630 | 824 | * |
| 4 | 13740 | * | 599 | 13050 | 691 | * | 13260 | * | 1004 |
| 5 | 14110 | 668 | * | 13780 | * | 697 | 14390 | 1028 | * |
| 6 | 14790 | * | 660 | 14580 | 732 | * | 15420 | * | 823 |
| 7 | 15150 | 61 | 681 | 14830 | 0 | 804 | 15700 | 872 | 18 |
| 8 | 15980 | 12 | 760 | 15670 | 4 | 863 | 16650 | 1059 | 130 |
| 9 | 16690 | 4 | 856 | 16490 | 5 | 860 | 17830 | 645 | 513 |
| 10 | 17510 | 4 | 967 | 17250 | 2 | 685 | 18080 | 376 | 832 |
| 11 | 18530 | 13 | 963 | 17780 | 10 | 780 | 19500 | 181 | 930 |
| 12 | 19740 | 3 | 996 | 18530 | 8 | 832 | 19810 | 211 | 953 |
| 13 | 20560 | 17 | 971 | 19310 | 24 | 757 | 20990 | 106 | 750 |
| 14 | 21160 | 17 | 954 | 19940 | 7 | 820 | 21760 | 98 | 764 |
| 15 | 22140 | 0 | 970 | 20500 | 6 | 798 | 21800 | 282 | 801 |
| 16 | 23040 | 44 | 1022 | 21260 | 0 | 779 | 22900 | 138 | 905 |
| 17 | 23950 | 99 | 980 | 21830 | 35 | 883 | 23510 | 150 | 959 |
| 18 | 24310 | 29 | 900 | 22610 | 12 | 954 | 24170 | 133 | 861 |
| 19 | 25660 | 11 | 800 | 23460 | 13 | 877 | 24800 | 89 | 976 |
| 20 | 25940 | 29 | 948 | 23960 | 48 | 868 | 25660 | 115 | 1075 |
| 21 | 26540 | 32 | 889 | 24880 | 13 | 798 | 26530 | 222 | 895 |
| 22 | 27650 | 5 | 891 | 25700 | 19 | 1156 | 26750 | 167 | 902 |
| 23 | 28670 | 11 | 990 | 26730 | 13 | 912 | 27460 | 210 | 966 |
| 24 | 29330 | 16 | 1109 | 27430 | 4 | 1022 | 28120 | 214 | 1139 |
| 25 | 30210 | 554 | 450 | 28130 | 14 | 1101 | 29280 | 526 | 821 |
| 26 | | 52 | 978 | 28730 | 0 | 1152 | 30500 | 652 | 606 |
| 27 | | 188 | 1126 | 29950 | 12 | 1065 | | 841 | 702 |
| 28 | | 41 | 1089 | | 6 | 1171 | | 1193 | 485 |
| 29 | | 41 | 1186 | | 2 | 1163 | | 854 | 576 |
| 30 | | 43 | 1317 | | 30 | 1098 | | 868 | 783 |
| 31 | | 16 | 1315 | | 7 | 1252 | | 519 | 787 |
| 32 | | | | | 157 | 1170 | | 977 | 682 |
| 33 | | | | | 135 | 1073 | | | |

| ROW | 40F LWT | 40FI A | 40FI B | 20M LWT | 20FI A | 20FI H | 21M LWT | 21FI A | 21FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12160 | * | 809 | 11920 | * | 487 | 11950 | 428 | * |
| 2 | 12330 | 850 | * | 12080 | 843 | * | 11950 | * | 433 |
| 3 | 13060 | * | 946 | 13080 | * | 693 | 12380 | 763 | * |
| 4 | 13730 | 1024 | * | 13520 | 930 | * | 13200 | * | 672 |
| 5 | 14690 | * | 1053 | 14150 | * | 686 | 13580 | 705 | * |
| 6 | 15130 | 874 | * | 14720 | 1031 | * | 14490 | * | 790 |
| 7 | 15710 | 793 | 145 | 15840 | 893 | 35 | 14580 | 749 | 2 |
| 8 | 16330 | 1017 | 89 | 16170 | 832 | 40 | 15280 | 896 | 2 |
| 9 | 17410 | 1004 | 10 | 16630 | 970 | 50 | 16160 | 888 | 161 |
| 10 | 17980 | 873 | 17 | 17470 | 957 | 28 | 16940 | 624 | 361 |
| 11 | 18280 | 1049 | 4 | 18150 | 894 | 108 | 17760 | 640 | 375 |
| 12 | 18800 | 1160 | 42 | 18870 | 761 | 246 | 18670 | 318 | 770 |
| 13 | 19870 | 1008 | 12 | 19270 | 995 | 188 | 19700 | 298 | 475 |
| 14 | 20420 | 706 | 15 | 20270 | 918 | 182 | 19800 | 11 | 1121 |
| 15 | 20620 | 1054 | 40 | 21030 | 926 | 162 | 20870 | 7 | 926 |
| 16 | 21260 | 1199 | 213 | 21660 | 1039 | 179 | 21820 | 13 | 962 |
| 17 | 22800 | 1195 | 137 | 22410 | 1099 | 106 | 22770 | 42 | 874 |
| 18 | 23740 | 1231 | 51 | 23090 | 1100 | 108 | 23270 | 313 | 599 |
| 19 | 24310 | 1235 | 61 | 24000 | 1106 | 106 | 24100 | 99 | 757 |
| 20 | 24910 | 912 | 412 | 25060 | 1018 | 87 | 24420 | 633 | 647 |
| 21 | 25870 | 1188 | 147 | 25600 | 1139 | 40 | 25810 | 752 | 352 |
| 22 | 26610 | 1235 | 23 | 26240 | 1213 | 79 | 26120 | 644 | 322 |
| 23 | 27250 | 1269 | 17 | 27190 | 1184 | 62 | 27000 | 120 | 1105 |
| 24 | 27850 | 1276 | 1 | 27890 | 1260 | 82 | 27830 | 579 | 628 |
| 25 | 28680 | 1250 | 6 | 28320 | 1371 | 67 | 28920 | 975 | 0 |
| 26 | 29660 | 832 | 318 | 29420 | 1390 | 106 | 29140 | 570 | 708 |
| 27 | 30190 | 1089 | 214 | 30250 | 1392 | 13 | 30050 | 390 | 400 |
| 28 | | 1241 | 73 | | 1476 | 49 | | 294 | 983 |
| 29 | | 1419 | 117 | | 1637 | 40 | | 516 | 917 |
| 30 | | 1450 | 131 | | 1599 | 30 | | 383 | 700 |
| 31 | | 1437 | 34 | | 1696 | 82 | | 756 | 408 |
| 32 | | 1531 | 60 | | 1743 | 16 | | 904 | 305 |
| 33 | | 1357 | 54 | | 1532 | 4 | | 987 | 255 |

| ROW | 38F LWT | 38FI A | 38FI H | 5F LWT | 5FI A | 5FI H | 25M LWT | 25FI B | 25FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12000 | * | 590 | 11690 | 499 | * | 12440 | 661 | * |
| 2 | 12460 | 770 | * | 11940 | * | 449 | 12850 | * | 655 |
| 3 | 13130 | * | 647 | 12140 | 820 | * | 13480 | 862 | * |
| 4 | 13580 | 827 | * | 12650 | * | 681 | 14280 | * | 666 |
| 5 | 13860 | * | 893 | 13350 | 840 | * | 14710 | 920 | * |
| 6 | 14930 | 1062 | * | 13810 | * | 806 | 15450 | * | 785 |
| 7 | 15910 | 409 | 623 | 14430 | 643 | 92 | 16270 | 852 | 2 |
| 8 | 16960 | 490 | 561 | 15110 | 698 | 271 | 16810 | 934 | 7 |
| 9 | 17540 | 351 | 695 | 15860 | 689 | 209 | 17700 | 991 | 4 |
| 10 | 18600 | 470 | 579 | 16620 | 587 | 186 | 18880 | 881 | 0 |
| 11 | 19350 | 465 | 651 | 17160 | 589 | 62 | 19240 | 894 | 0 |
| 12 | 20380 | 368 | 649 | 17460 | 560 | 159 | 19770 | 925 | 3 |
| 13 | 20950 | 538 | 567 | 17790 | 747 | 215 | 20290 | 910 | 4 |
| 14 | 21930 | 370 | 666 | 18730 | 718 | 242 | 21420 | 1110 | 5 |
| 15 | 22940 | 360 | 794 | 19330 | 966 | 169 | 22500 | 950 | 7 |
| 16 | 23520 | 350 | 955 | 20450 | 1055 | 139 | 23110 | 943 | 9 |
| 17 | 24640 | 631 | 508 | 21210 | 1108 | 169 | 23570 | 1093 | 28 |
| 18 | 25500 | 566 | 613 | 22210 | 1131 | 13 | 24710 | 1099 | 18 |
| 19 | 26410 | 636 | 757 | 22980 | 901 | 90 | 25380 | 1111 | 47 |
| 20 | 27340 | 786 | 549 | 23620 | 807 | 231 | 26360 | 1203 | 53 |
| 21 | 28460 | 937 | 436 | 23820 | 750 | 52 | 27570 | 1139 | 63 |
| 22 | 29340 | 838 | 613 | 23970 | 758 | 81 | 28190 | 1225 | 5 |
| 23 | 30390 | 947 | 476 | 24740 | 619 | 323 | 28890 | 1328 | 95 |
| 24 | | 796 | 497 | 25700 | 301 | 165 | 29770 | 1226 | 71 |
| 25 | | 810 | 687 | 25400 | 825 | 163 | 30730 | 801 | 562 |
| 26 | | 733 | 671 | 26350 | 905 | 181 | | 948 | 306 |
| 27 | | 981 | 412 | 27350 | 873 | 107 | | 1153 | 93 |
| 28 | | 1186 | 587 | 27720 | 1098 | 86 | | 1060 | 330 |
| 29 | | 702 | 795 | 28620 | 1225 | 53 | | 1173 | 420 |
| 30 | | | | 29370 | 802 | 63 | | 1367 | 289 |
| 31 | | | | | 612 | 15 | | 1400 | 83 |
| 32 | | | | | 775 | 10 | | | |
| 33 | | | | | 900 | 12 | | | |
| 34 | | | | | 1405 | 231 | | | |
| 35 | | | | | 1436 | 11 | | | |
| 36 | | | | | 1574 | 29 | | | |

| ROW | 3M LWT | 3FI B | 3FI H | 6F LWT | 6FI B | 6FI H | 30F LWT | 30FI B | 30FI H |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12120 | * | 602 | 12620 | * | 648 | 12170 | 649 | * |
| 2 | 12730 | 715 | * | 13050 | 945 | * | 12790 | * | 585 |
| 3 | 13510 | * | 715 | 14100 | * | 788 | 13180 | 957 | * |
| 4 | 14250 | 828 | * | 14800 | 1009 | * | 14060 | * | 682 |
| 5 | 14780 | * | 723 | 15720 | * | 783 | 14830 | 819 | * |
| 6 | 15430 | 791 | * | 16300 | 873 | * | 15540 | * | 788 |
| 7 | 16210 | 800 | 75 | 17040 | 783 | 0 | 16350 | 1019 | 5 |
| 8 | 17030 | 699 | 37 | 17520 | 741 | 5 | 17140 | 990 | 58 |
| 9 | 17590 | 879 | 11 | 18160 | 888 | 14 | 18130 | 1060 | 5 |
| 10 | 18400 | 782 | 52 | 18830 | 981 | 26 | 18780 | 992 | 7 |
| 11 | 19080 | 863 | 2 | 20120 | 1051 | 26 | 19670 | 1180 | 12 |
| 12 | 19660 | 892 | 2 | 20870 | 1027 | 13 | 20730 | 1112 | 20 |
| 13 | 20530 | 885 | 1 | 21480 | 1132 | 0 | 21710 | 1089 | 10 |
| 14 | 21350 | 858 | 2 | 22440 | 1282 | 5 | 22410 | 1157 | 21 |
| 15 | 21960 | 905 | 0 | 23350 | 1209 | 0 | 23190 | 1133 | 5 |
| 16 | 22690 | 903 | 3 | 23930 | 1211 | 3 | 23810 | 1048 | 0 |
| 17 | 23480 | 795 | 16 | 24670 | 1104 | 7 | 24340 | 1123 | 0 |
| 18 | 24080 | 940 | 2 | 25610 | 1079 | 14 | 25260 | 1178 | 0 |
| 19 | 24820 | 900 | 1 | 26540 | 1197 | 7 | 25700 | 1128 | 28 |
| 20 | 25480 | 949 | 17 | 26740 | 1174 | 2 | 26220 | 1052 | 10 |
| 21 | 26290 | 877 | 66 | 27760 | 1195 | 1 | 27400 | 1255 | 2 |
| 22 | 27190 | 1030 | 58 | 28570 | 1274 | 4 | 28140 | 1282 | 140 |
| 23 | 28130 | 924 | 45 | 29300 | 1183 | 4 | 28900 | 1149 | 0 |
| 24 | 28780 | 1182 | 10 | 29910 | 1218 | 20 | | | . |
| 25 | 29700 | 1057 | 40 | 30650 | 1287 | 0 | | | |
| 26 | | 1255 | 14 | | 1363 | 15 | | | |
| 27 | | 1384 | 4 | | 1434 | 0 | | | |
| 28 | | 1444 | 11 | | 1585 | 0 | | | |
| 29 | | 1728 | 0 | | 1168 | 154 | | | |
| 30 | | 1654 | 0 | | 1481 | 16 | | | |
| 31 | | 1518 | 0 | | 1414 | 14 | | | |

| ROW | 32F LWT | 32FI L | 19F LWT | 19FI L | 17M LWT | 17FI L | 2M LWT | 2FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 12250 | 515 | 12160 | 630 | 12090 | 718 | 11830 | 409 |
| 2 | 12360 | 672 | 12530 | 618 | 12490 | 538 | 12310 | 505 |
| 3 | 12760 | 663 | 12740 | 524 | 12720 | 734 | 12240 | 673 |
| 4 | 12890 | 897 | 12750 | 542 | 12780 | 766 | 12870 | 725 |
| 5 | 13760 | 753 | 13010 | 583 | 13280 | 788 | 12800 | 671 |
| 6 | 14280 | 827 | 13240 | 582 | 13620 | 744 | 13650 | 457 |
| 7 | 14290 | 884 | 13460 | 600 | 14040 | 490 | 13370 | 520 |
| 8 | 14860 | 758 | 13680 | 483 | 13980 | 691 | 13570 | 515 |
| 9 | 15090 | 1013 | 14050 | 556 | 14510 | 511 | 13770 | 518 |
| 10 | 15790 | 1116 | 13970 | 587 | 14290 | 930 | 14000 | 636 |
| 11 | 16590 | 1233 | 14300 | 691 | 15110 | 865 | 14470 | 837 |
| 12 | 17370 | 1201 | 14790 | 697 | 15490 | 757 | 14990 | 757 |
| 13 | 18040 | 1170 | 15170 | 706 | 15720 | 936 | 15220 | 1037 |
| 14 | 18890 | 1220 | 15540 | 700 | 15990 | 750 | 15920 | 861 |
| 15 | 19430 | 580 | 15870 | 865 | 16440 | 993 | 16270 | 885 |
| 16 | 19090 | 590 | 16390 | 973 | 17120 | 939 | 16660 | 1021 |
| 17 | 19240 | 1019 | 17110 | 1011 | 17500 | 1017 | 17200 | 905 |
| 18 | 19790 | 1188 | 17840 | 927 | 18040 | 1183 | 17700 | 921 |
| 19 | 20690 | 1114 | 18000 | 1032 | 18610 | 1210 | 18100 | 795 |
| 20 | 21590 | 1156 | 18760 | 1044 | 18990 | 1171 | 18420 | 862 |
| 21 | 22160 | 1166 | 19230 | 1012 | 19600 | 1244 | 18920 | 838 |
| 22 | 22840 | 1114 | 19530 | 972 | 20130 | 1405 | 19400 | 882 |
| 23 | 23160 | 1130 | 20010 | 1152 | 21100 | 1379 | 19820 | 857 |
| 24 | 23530 | 1301 | 20900 | 1172 | 21930 | 1477 | 20190 | 859 |
| 25 | 24420 | 1279 | 21450 | 1235 | 22620 | 1483 | 20570 | 1031 |
| 26 | 25090 | 1248 | 22380 | 1265 | 23330 | 1485 | 21150 | 1025 |
| 27 | 25510 | 1430 | 22740 | 1339 | 23950 | 1383 | 21550 | 1092 |
| 28 | 26510 | 1556 | 23600 | 1495 | 24810 | 1178 | 22240 | 1072 |
| 29 | 27560 | 1521 | 24350 | 1438 | 25130 | 1151 | 22820 | 870 |
| 30 | 28080 | 1502 | 25240 | 1547 | 25260 | 1399 | 22920 | 965 |
| 31 | 28950 | 1448 | 26160 | 1566 | 26070 | 1327 | 23490 | 1074 |
| 32 | 29760 | | 26970 | 1469 | 26670 | 1549 | 24010 | 991 |
| 33 | | | 27430 | 1449 | 27500 | 1585 | 24530 | 976 |
| 34 | | | 28180 | 1429 | 28370 | 1480 | 24900 | 1010 |
| 35 | | | 28620 | 1213 | 28940 | 1244 | 25380 | 924 |
| 36 | | | 29010 | 1483 | 29550 | | 25780 | 1132 |
| 37 | | | 30080 | | | | 26100 | 1134 |
| 38 | | | | | | | 27050 | 1076 |
| 39 | | | | | | | 27240 | 1019 |
| 40 | | | | | | | 27470 | 985 |
| 41 | | | | | | | 28320 | 1055 |
| 42 | | | | | | | 28690 | 1070 |
| 43 | | | | | | | 28770 | 1013 |
| 44 | | | | | | | 29270 | |

| ROW | 29F LWT | 29FI A | 39F LWT | 39FI A | 12M LWT | 12FI A | 4M LWT | 4FI A |
|---|---|---|---|---|---|---|---|---|
| 1 | 11940 | 619 | 12440 | 607 | 11960 | 373 | 12000 | 628 |
| 2 | 12300 | 621 | 12680 | 620 | 12360 | 558 | 12910 | 410 |
| 3 | 12740 | 723 | 13340 | 774 | 12740 | 530 | 12510 | 504 |
| 4 | 13280 | 679 | 13730 | 775 | 13080 | 559 | 12910 | 753 |
| 5 | 13890 | 639 | 14270 | 815 | 13620 | 645 | 13480 | 683 |
| 6 | 14150 | 805 | 14390 | 929 | 13950 | 618 | 14110 | 809 |
| 7 | 14950 | 932 | 15390 | 995 | 14310 | 679 | 14780 | 789 |
| 8 | 15330 | 920 | 15940 | 1064 | 14810 | 722 | 15310 | 851 |
| 9 | 15920 | 1003 | 16680 | 1086 | 15200 | 740 | 15700 | 726 |
| 10 | 17050 | 861 | 17690 | 1137 | 15720 | 684 | 16010 | 829 |
| 11 | 17660 | 902 | 18170 | 1061 | 15770 | 619 | 16880 | 904 |
| 12 | 18000 | 1118 | 19200 | 619 | 16390 | 714 | 17370 | 858 |
| 13 | 18990 | 1091 | 19210 | 961 | 17000 | 864 | 18020 | 901 |
| 14 | 19510 | 1118 | 19840 | 1134 | 17660 | 900 | 18590 | 799 |
| 15 | 20070 | 1201 | 20620 | 1221 | 18260 | 851 | 19240 | 958 |
| 16 | 21060 | 1221 | 21170 | 1353 | 18770 | 886 | 19890 | 988 |
| 17 | 21660 | 1324 | 22150 | 1464 | 19450 | 1045 | 20690 | 936 |
| 18 | 23020 | 1272 | 23190 | 1491 | 20190 | 1128 | 21270 | 919 |
| 19 | 23450 | 1159 | 24100 | 953 | 20910 | 1066 | 21670 | 1111 |
| 20 | 24110 | 1040 | 24570 | 1142 | 21510 | 900 | 22720 | 1037 |
| 21 | 24720 | 1039 | 25010 | 1033 | 22230 | 1014 | 23510 | 1126 |
| 22 | 25380 | 1254 | 25360 | 1145 | 22830 | 1069 | 23960 | 993 |
| 23 | 26190 | 1358 | 26160 | 1179 | 23690 | 1107 | 24590 | 1143 |
| 24 | 26990 | 1389 | 26810 | 1196 | 24560 | 964 | 25150 | 1071 |
| 25 | 27890 | 1320 | 27620 | 1254 | 25010 | 912 | 25810 | 1162 |
| 26 | 28560 | 1134 | 28180 | 1371 | 25630 | 1130 | 26690 | 1259 |
| 27 | 29090 | 1236 | 29040 | 1374 | 26510 | 1046 | 27400 | 1251 |
| 28 | 29910 | | 30200 | | 27120 | 984 | 28410 | 1006 |
| 29 | | | | | 27560 | 1087 | 28890 | 1026 |
| 30 | | | | | 28580 | 1189 | 29330 | 1213 |
| 31 | | | | | 29380 | 1156 | 30060 | |
| 32 | | | | | 30150 | | | |

| ROW | 7M LWT | 7FI B | 17aM LWT | 17FI B | 24F LWT | 24FI B | 27F LWT | 27FI B |
|---|---|---|---|---|---|---|---|---|
| 1 | 11990 | 548 | 12070 | 555 | 12280 | 438 | 11840 | 474 |
| 2 | 12580 | 555 | 12860 | 723 | 12320 | 494 | 12230 | 535 |
| 3 | 13050 | 656 | 13190 | 684 | 12800 | 560 | 12700 | 768 |
| 4 | 13790 | 620 | 14010 | 710 | 13470 | 717 | 13590 | 889 |
| 5 | 14290 | 513 | 14630 | 871 | 14330 | 828 | 14060 | 859 |
| 6 | 14700 | 642 | 15230 | 986 | 14980 | 669 | 14980 | 712 |
| 7 | 15240 | 684 | 16420 | 946 | 15590 | 719 | 15520 | 676 |
| 8 | 15820 | 739 | 17440 | 910 | 16180 | 860 | 15960 | 845 |
| 9 | 16350 | 844 | 17900 | 932 | 16990 | 831 | 16760 | 934 |
| 10 | 17300 | 824 | 18720 | 825 | 17680 | 876 | 17590 | 1026 |
| 11 | 18000 | 863 | 18810 | 969 | 18500 | 964 | 18320 | 880 |
| 12 | 18800 | 833 | 19620 | 1014 | 19450 | 960 | 19410 | 802 |
| 13 | 19560 | 851 | 20930 | 1167 | 20070 | 1106 | 19700 | 900 |
| 14 | 20230 | 827 | 21900 | 1247 | 21070 | 1135 | 20120 | 1039 |
| 15 | 20930 | 920 | 22630 | 1283 | 21760 | 1187 | 21110 | 1268 |
| 16 | 21610 | 865 | 23710 | 1201 | 22520 | 1235 | 21900 | 1240 |
| 17 | 22510 | 892 | 24480 | 1281 | 23460 | 1234 | 23070 | 1321 |
| 18 | 23190 | 1048 | 25520 | 1127 | 24520 | 977 | 24160 | 1178 |
| 19 | 24090 | 956 | 26300 | 1053 | 25000 | 1234 | 24980 | 1153 |
| 20 | 24990 | 852 | 27310 | 1235 | 25590 | 1293 | 25980 | 1256 |
| 21 | 25500 | 998 | 28370 | 1286 | 26710 | 1232 | 26850 | 1275 |
| 22 | 26390 | 1156 | 28840 | 1293 | 28340 | 1131 | 27290 | 1299 |
| 23 | 27380 | 1100 | 29660 | | 27910 | 1233 | 28140 | 1300 |
| 24 | 28080 | 1103 | | | 28880 | 1297 | 28870 | 1235 |
| 25 | 28870 | 1009 | | | 29730 | 1212 | 29470 | 1144 |
| 26 | 29440 | 1325 | | | 30700 | | 29820 | |
| 27 | 30570 | | | | | | | |

| ROW | 37M LWT | 37FI H | 14M LWT | 14FI H | 9F LWT | 9FI H | 34F LWT | 34FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 11760 | 499 | 12180 | 438 | 12480 | 768 | 12120 | 560 |
| 2 | 11990 | 758 | 13180 | 534 | 13350 | 724 | 12790 | 478 |
| 3 | 12870 | 510 | 13580 | 562 | 13840 | 705 | 13040 | 792 |
| 4 | 13470 | 569 | 14080 | 606 | 14710 | 506 | 13890 | 685 |
| 5 | 13970 | 516 | 15030 | 547 | 14830 | 589 | 14610 | 781 |
| 6 | 14390 | 764 | 15490 | 526 | 15330 | 816 | 15440 | 748 |
| 7 | 15140 | 831 | 15950 | 663 | 16100 | 956 | 16110 | 787 |
| 8 | 15920 | 760 | 16520 | 622 | 17190 | 1004 | 16760 | 860 |
| 9 | 16630 | 760 | 17160 | 739 | 18210 | 927 | 17510 | 761 |
| 10 | 17440 | 733 | 18070 | 864 | 19020 | 959 | 17870 | 817 |
| 11 | 18410 | 606 | 18870 | 633 | 19770 | 1113 | 18510 | 1042 |
| 12 | 18540 | 806 | 19270 | 787 | 20640 | 1071 | 19690 | 899 |
| 13 | 19510 | 784 | 19770 | 642 | 21420 | 1148 | 20370 | 887 |
| 14 | 20160 | 654 | 20580 | 899 | 22230 | 795 | 20860 | 897 |
| 15 | 20740 | 828 | 21270 | 781 | 22470 | 1117 | 21600 | 975 |
| 16 | 21430 | 943 | 22190 | 961 | 23670 | 1068 | 22530 | 870 |
| 17 | 22330 | 870 | 23070 | 1101 | 24600 | 1144 | 22660 | 858 |
| 18 | 23110 | 862 | 23580 | 1139 | 25350 | 1135 | 23510 | 931 |
| 19 | 23450 | 959 | 25090 | 963 | 26070 | 1199 | 24080 | 1093 |
| 20 | 24650 | 850 | 25510 | 1165 | 26670 | 1158 | 24880 | 880 |
| 21 | 25070 | 991 | 26630 | 1179 | 27420 | 1211 | 25390 | 1240 |
| 22 | 25920 | 952 | 27500 | 1086 | 29010 | 1059 | 26350 | 1314 |
| 23 | 26520 | 704 | 28000 | 929 | 28840 | 1224 | 27030 | 961 |
| 24 | 26760 | 814 | 28390 | 1097 | 29810 | | 27600 | 1172 |
| 25 | 27210 | 396 | 29400 | 1042 | | | 28500 | 667 |
| 26 | 26650 | 826 | 30040 | | | | 28410 | 1135 |
| 27 | 28560 | 950 | | | | | 29130 | 1262 |
| 28 | 29170 | 1232 | | | | | 29900 | |
| 29 | 29810 | | | | | | | |

## E. Liveweight and Feed Intake Data - Experiment 5

1-40 = Pig Identity; M or F = Sex; LWT = Liveweight (g); FI = Feed Intake (g); L, A, B or H = Feed.

### (i) Period A

| ROW | 12M LWT | 12FI L | 6M LWT | 6FI L | 3M LWT | 3FI L | 7M LWT | 7FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 8130 | 10 | 6880 | 91 | 8170 | 32 | 6420 | 54 |
| 2 | 7860 | 184 | 6840 | 184 | 8120 | 196 | 6390 | 97 |
| 3 | 8250 | 327 | 7180 | 260 | 8520 | 344 | 6360 | 134 |
| 4 | 8760 | 419 | 7600 | 219 | 8730 | 393 | 6430 | 232 |
| 5 | 9110 | 443 | 7660 | 289 | 9200 | 225 | 6660 | 256 |
| 6 | 9270 | 543 | 8030 | 310 | 9090 | 113 | 6830 | 260 |
| 7 | 9440 | 410 | 8270 | 369 | 8900 | 169 | 7100 | 275 |
| 8 | 9670 | 276 | 8660 | 393 | 9120 | 220 | 7320 | 315 |
| 9 | 9730 | 280 | 9060 | 349 | 9240 | 253 | 7600 | 346 |
| 10 | 9850 | 280 | 9170 | 400 | 9510 | 387 | 7680 | 345 |
| 11 | 9720 | 456 | 9400 | 512 | 9560 | 480 | 7900 | 410 |
| 12 | 10120 | 625 | 9730 | 555 | 9990 | 324 | 7970 | 438 |
| 13 | 10780 | 737 | 10110 | 616 | 10140 | 378 | 8340 | 433 |
| 14 | 11510 | 728 | 10610 | 643 | 10430 | 424 | 8510 | 580 |
| 15 | 11830 | 763 | 11050 | 649 | 10630 | 481 | 9000 | 619 |
| 16 | 12110 | 828 | 11020 | 696 | 10970 | 570 | 9370 | 591 |
| 17 | 12520 | 810 | 11420 | 809 | 11270 | 712 | 9680 | 663 |
| 18 | 12860 | 603 | 11790 | 795 | 11550 | 711 | 10000 | 633 |
| 19 | 13160 | 850 | 12200 | 803 | 12110 | 824 | 10430 | 743 |
| 20 | 13810 | 915 | 12720 | 650 | 12500 | 870 | 10880 | 710 |
| 21 | 14210 | 1014 | 13110 | 813 | 12840 | 927 | 11180 | 830 |
| 22 | 14680 | 1096 | 13300 | 814 | 13160 | 942 | 11850 | 740 |
| 23 | 15190 | 1088 | 13910 | 629 | 13660 | 828 | 12110 | 628 |
| 24 | 15840 | 1006 | 14050 | 727 | 14260 | 708 | 12480 | 662 |
| 25 | 16780 | 1180 | 14580 | 769 | 14520 | 998 | 12750 | 690 |
| 26 | 17480 | 1099 | 15050 | 818 | 14880 | 938 | 13070 | 802 |
| 27 | 18290 | 1290 | 15680 | 1012 | 15380 | 967 | 13720 | 844 |
| 28 | 19180 | 1133 | 17040 | 1006 | 15880 | 1038 | 14090 | 890 |
| 29 | 19910 | | 17650 | 1150 | 17040 | 1173 | 14650 | 903 |
| 30 | | | 18810 | 949 | 17710 | 1137 | 15120 | 952 |
| 31 | | | 19390 | 1138 | 19010 | 1265 | 15570 | 887 |
| 32 | | | 20480 | | 20010 | 1324 | 16650 | 993 |
| 33 | | | | | 21020 | | 17050 | 917 |
| 34 | | | | | | | 18110 | 999 |
| 35 | | | | | | | 18390 | 915 |
| 36 | | | | | | | 19180 | |

| ROW | 18M LWT | 18FI L | 14M LWT | 14FI L | 19M LWT | 19FI L | 22M LWT | 22FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 7770 | 40 | 6770 | 98 | 6900 | 71 | 5090 | 35 |
| 2 | 7590 | 185 | 6890 | 200 | 6800 | 200 | 4840 | 92 |
| 3 | 7760 | 293 | 6990 | 287 | 7100 | 261 | 5080 | 164 |
| 4 | 8120 | 199 | 7340 | 246 | 7320 | 196 | 5380 | 214 |
| 5 | 8010 | 172 | 7380 | 243 | 7500 | 138 | 5820 | 281 |
| 6 | 8120 | 205 | 7500 | 281 | 7510 | 153 | 6190 | 334 |
| 7 | 8260 | 277 | 7730 | 333 | 7450 | 169 | 6540 | 301 |
| 8 | 8380 | 330 | 7900 | 385 | 7280 | 300 | 6740 | 290 |
| 9 | 8670 | 483 | 8130 | 441 | 7730 | 361 | 6900 | 308 |
| 10 | 9010 | 479 | 8490 | 443 | 7920 | 380 | 6950 | 299 |
| 11 | 9280 | 577 | 8740 | 518 | 8220 | 445 | 7010 | 368 |
| 12 | 9570 | 349 | 8940 | 522 | 8660 | 498 | 7270 | 452 |
| 13 | 9550 | 518 | 9250 | 508 | 8800 | 472 | 7530 | 464 |
| 14 | 9710 | 658 | 9570 | 468 | 9030 | 491 | 7820 | 420 |
| 15 | 10130 | 809 | 9740 | 434 | 9180 | 652 | 8020 | 399 |
| 16 | 10700 | 583 | 9940 | 537 | 9530 | 600 | 8260 | 480 |
| 17 | 10870 | 624 | 10240 | 630 | 9970 | 677 | 8520 | 588 |
| 18 | 10790 | 838 | 10630 | 646 | 10270 | 664 | 8910 | 705 |
| 19 | 11380 | 683 | 10930 | 696 | 10500 | 686 | 9250 | 588 |
| 20 | 11500 | 697 | 11180 | 635 | 10970 | 633 | 9430 | 621 |
| 21 | 12080 | 705 | 11310 | 700 | 11090 | 600 | 9760 | 753 |
| 22 | 12420 | 858 | 11870 | 689 | 11530 | 625 | 10290 | 805 |
| 23 | 13030 | 892 | 12250 | 622 | 11820 | 575 | 10660 | 782 |
| 24 | 13310 | 967 | 12390 | 757 | 12150 | 684 | 11080 | 696 |
| 25 | 13710 | 1015 | 12690 | 831 | 12520 | 793 | 11290 | 866 |
| 26 | 14100 | 1010 | 13320 | 846 | 12740 | 822 | 11760 | 807 |
| 27 | 14860 | 1130 | 13680 | 806 | 13300 | 768 | 12420 | 860 |
| 28 | 15500 | 1168 | 13970 | 907 | 13660 | 796 | 12880 | 881 |
| 29 | 16140 | 1002 | 14280 | 932 | 13970 | 805 | 13290 | 890 |
| 30 | 16810 | 1271 | 14940 | 862 | 14510 | 824 | 13690 | 981 |
| 31 | 17830 | 1250 | 15410 | 910 | 14830 | 854 | 14410 | 807 |
| 32 | 18870 | 1082 | 15660 | 1062 | 15380 | 756 | 14710 | 1022 |
| 33 | 19710 | 1155 | 17190 | 1117 | 15620 | 1027 | 15360 | 1010 |
| 34 | 20410 | | 17650 | 1136 | 16990 | 825 | 15870 | 926 |
| 35 | | | 18920 | 1070 | 17160 | 1061 | 17050 | 1099 |
| 36 | | | 19460 | 1322 | 18700 | 919 | 17680 | 1087 |
| 37 | | | 20910 | | 19000 | 979 | 18620 | 1234 |
| 38 | | | | | 19960 | | 19760 | 1321 |
| 39 | | | | | | | 20900 | |

| ROW | 21M LWT | 21FI L | 28M LWT | 28FI L | 1F LWT | 1FI L | 40F LWT | 40FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 5610 | 13 | 4930 | 90 | 8120 | 40 | 7970 | 30 |
| 2 | 5280 | 74 | 4970 | 93 | 7950 | 134 | 7960 | 189 |
| 3 | 5310 | 246 | 5050 | 125 | 8050 | 117 | 8250 | 231 |
| 4 | 5880 | 282 | 5220 | 203 | 8180 | 156 | 8410 | 148 |
| 5 | 6230 | 231 | 5350 | 182 | 8230 | 114 | 8370 | 160 |
| 6 | 6370 | 296 | 5710 | 191 | 8250 | 99 | 8420 | 283 |
| 7 | 6580 | 273 | 5950 | 233 | 8300 | 248 | 8690 | 353 |
| 8 | 6640 | 268 | 6030 | 233 | 8400 | 294 | 9050 | 326 |
| 9 | 6570 | 293 | 6150 | 250 | 8800 | 327 | 9100 | 229 |
| 10 | 6840 | 329 | 6330 | 266 | 9150 | 449 | 9000 | 108 |
| 11 | 7070 | 390 | 6560 | 287 | 9600 | 542 | 8650 | 112 |
| 12 | 7360 | 401 | 6550 | 222 | 9860 | 535 | 8480 | 128 |
| 13 | 7610 | 401 | 6400 | 195 | 10330 | 572 | 8350 | 321 |
| 14 | 7810 | 387 | 6260 | 274 | 10640 | 655 | 8860 | 400 |
| 15 | 8010 | 422 | 6380 | 373 | 10860 | 767 | 9520 | 589 |
| 16 | 8370 | 466 | 6810 | 367 | 11320 | 865 | 10260 | 657 |
| 17 | 8620 | 449 | 7040 | 340 | 11820 | 904 | 10800 | 654 |
| 18 | 8730 | 523 | 7040 | 506 | 12320 | 1018 | 11160 | 680 |
| 19 | 8980 | 549 | 7190 | 410 | 13050 | 1031 | 11280 | 768 |
| 20 | 9210 | 568 | 7470 | 411 | 13600 | 1040 | 11660 | 589 |
| 21 | 9610 | 603 | 7670 | 450 | 14120 | 1085 | 11690 | 524 |
| 22 | 9910 | 571 | 7870 | 520 | 14650 | 1136 | 12020 | 510 |
| 23 | 10170 | 633 | 7950 | 480 | 15110 | 1090 | 12050 | 687 |
| 24 | 10430 | 703 | 8340 | 483 | 15740 | 665 | 12650 | 688 |
| 25 | 10910 | 706 | 8550 | 675 | 16280 | 1166 | 13060 | 715 |
| 26 | 11340 | 696 | 9020 | 586 | 17140 | 952 | 13170 | 780 |
| 27 | 11670 | 675 | 9550 | 561 | 17770 | 1239 | 13750 | 944 |
| 28 | 11890 | 648 | 9340 | 578 | 18710 | 1210 | 14180 | 958 |
| 29 | 12310 | 728 | 9690 | 660 | 19560 | | 14640 | 955 |
| 30 | 12820 | 771 | 9970 | 728 | | | 15130 | 612 |
| 31 | 13140 | 656 | 10470 | 746 | | | 15200 | 799 |
| 32 | 13620 | 713 | 10870 | 737 | | | 15660 | 789 |
| 33 | 13890 | 758 | 11570 | 724 | | | 16300 | 954 |
| 34 | 14210 | 587 | 11640 | 698 | | | 16920 | 935 |
| 35 | 14160 | 708 | 12460 | 709 | | | 18050 | 990 |
| 36 | 14510 | 676 | 12200 | 902 | | | 18690 | 940 |
| 37 | 14710 | 652 | 12480 | 919 | | | 19540 | |
| 38 | 14880 | 700 | 13610 | 770 | | | | |
| 39 | 15280 | 662 | 13120 | 1003 | | | | |
| 40 | 15500 | 489 | 14590 | 1050 | | | | |
| 41 | 15370 | 701 | 14810 | 911 | | | | |
| 42 | 15980 | 878 | 14460 | 856 | | | | |
| 43 | 16920 | 655 | 14690 | 829 | | | | |
| 44 | 17190 | 1177 | 15100 | 971 | | | | |
| 45 | 19000 | 909 | 15280 | 1027 | | | | |
| 46 | 19210 | 1454 | 16100 | 1029 | | | | |
| 47 | 21360 | | 17190 | 1007 | | | | |
| 48 | | | 17390 | 939 | | | | |
| 49 | | | 18420 | 999 | | | | |
| 50 | | | 18660 | 1273 | | | | |
| 51 | | | 20340 | | | | | |

| ROW | 13F LWT | 13FI L | 27F LWT | 27FI L | 30F LWT | 30FI L | 34F LWT | 34FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 7570 | 20 | 6970 | 100 | 6740 | 24 | 7780 | 23 |
| 2 | 7360 | 173 | 6630 | 300 | 6430 | 140 | 7320 | 74 |
| 3 | 7770 | 226 | 6850 | 450 | 6780 | 118 | 7240 | 224 |
| 4 | 8050 | 192 | 7390 | 496 | 6740 | 157 | 7690 | 50 |
| 5 | 8070 | 310 | 7790 | 525 | 6930 | 175 | 6950 | 5 |
| 6 | 8350 | 237 | 8020 | 450 | 7110 | 215 | 6700 | 40 |
| 7 | 8540 | 237 | 8120 | 399 | 7300 | 230 | 6690 | 159 |
| 8 | 8720 | 296 | 8210 | 507 | 7380 | 267 | 7000 | 237 |
| 9 | 8630 | 274 | 8600 | 626 | 7550 | 308 | 7350 | 305 |
| 10 | 8670 | 356 | 9080 | 664 | 7750 | 310 | 7650 | 321 |
| 11 | 8670 | 340 | 9380 | 684 | 7850 | 351 | 7870 | 249 |
| 12 | 8810 | 491 | 9580 | 692 | 8000 | 416 | 7700 | 339 |
| 13 | 9050 | 525 | 9860 | 575 | 8310 | 395 | 7790 | 392 |
| 14 | 9380 | 557 | 10090 | 696 | 8540 | 549 | 8240 | 397 |
| 15 | 9720 | 534 | 10550 | 694 | 8990 | 514 | 8570 | 493 |
| 16 | 9970 | 596 | 10970 | 905 | 9150 | 499 | 9100 | 510 |
| 17 | 10270 | 668 | 11500 | 909 | 9450 | 563 | 9260 | 438 |
| 18 | 10540 | 790 | 11890 | 813 | 9600 | 507 | 9370 | 587 |
| 19 | 11190 | 894 | 12290 | 879 | 9780 | 530 | 9690 | 656 |
| 20 | 11540 | 767 | 12770 | 953 | 10310 | 540 | 10190 | 623 |
| 21 | 11860 | 750 | 13240 | 836 | 10600 | 653 | 10460 | 697 |
| 22 | 12230 | 739 | 13730 | 1025 | 10820 | 699 | 10970 | 745 |
| 23 | 12610 | 789 | 14190 | 1053 | 11220 | 792 | 11230 | 695 |
| 24 | 12840 | 913 | 14650 | 1033 | 11740 | 815 | 11580 | 610 |
| 25 | 13520 | 877 | 15330 | 1073 | 12100 | 816 | 11950 | 745 |
| 26 | 14070 | 835 | 16080 | 1049 | 12620 | 775 | 12400 | 775 |
| 27 | 14350 | 819 | 16910 | 1121 | 12920 | 665 | 12830 | 686 |
| 28 | 14680 | 809 | 17400 | 1027 | 13330 | 832 | 13020 | 750 |
| 29 | 15130 | 742 | 18190 | 995 | 13540 | 940 | 13550 | 804 |
| 30 | 15330 | 918 | 18300 | | 14240 | 887 | 13930 | 796 |
| 31 | 15640 | 1117 | | | 14740 | 881 | 14270 | 731 |
| 32 | 17070 | 989 | | | 14940 | 882 | 14560 | 850 |
| 33 | 18140 | 1258 | | | 15510 | 856 | 15230 | 870 |
| 34 | 18900 | 1144 | | | 16310 | 1039 | 15710 | 955 |
| 35 | 19640 | 1336 | | | 17020 | 1003 | 16680 | 868 |
| 36 | 20490 | | | | 18020 | 1080 | 17220 | 976 |
| 37 | | | | | 19020 | 1025 | 18350 | 1101 |
| 38 | | | | | 19460 | | 18910 | 1284 |
| 39 | | | | | | | 20310 | |

| ROW | 29F LWT | 29FI L | 39F LWT | 39FI L | 24F LWT | 24FI L | 36F LWT | 36FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 5760 | 90 | 6420 | 60 | 6030 | 43 | 5960 | 21 |
| 2 | 5600 | 168 | 6260 | 28 | 6000 | 146 | 5510 | 17 |
| 3 | 5830 | 290 | 5570 | 25 | 6190 | 123 | 5380 | 25 |
| 4 | 6150 | 240 | 5650 | 182 | 6130 | 71 | 5250 | 109 |
| 5 | 6380 | 250 | 6000 | 221 | 6000 | 122 | 5320 | 170 |
| 6 | 6360 | 350 | 6370 | 293 | 6190 | 182 | 5410 | 201 |
| 7 | 6470 | 298 | 6690 | 362 | 6400 | 204 | 5600 | 143 |
| 8 | 6720 | 292 | 7050 | 428 | 6520 | 210 | 5690 | 130 |
| 9 | 6780 | 425 | 7370 | 457 | 6530 | 227 | 5660 | 237 |
| 10 | 7260 | 430 | 7550 | 456 | 6490 | 271 | 5920 | 316 |
| 11 | 7520 | 441 | 7670 | 470 | 6500 | 374 | 6180 | 315 |
| 12 | 7670 | 491 | 7790 | 357 | 6760 | 376 | 6410 | 318 |
| 13 | 7950 | 491 | 7900 | 370 | 7000 | 313 | 6560 | 310 |
| 14 | 8210 | 550 | 8100 | 550 | 7170 | 501 | 6630 | 299 |
| 15 | 8450 | 584 | 8560 | 557 | 7440 | 423 | 6830 | 385 |
| 16 | 8790 | 556 | 8780 | 615 | 7480 | 495 | 7030 | 454 |
| 17 | 8970 | 550 | 9230 | 743 | 7680 | 554 | 7340 | 508 |
| 18 | 9170 | 628 | 9650 | 747 | 8140 | 581 | 7670 | 520 |
| 19 | 9610 | 622 | 10030 | 765 | 8440 | 517 | 7880 | 270 |
| 20 | 9880 | 731 | 10510 | 717 | 8620 | 579 | 7570 | 457 |
| 21 | 10410 | 703 | 10820 | 660 | 9020 | 762 | 8030 | 515 |
| 22 | 10720 | 738 | 11110 | 611 | 9380 | 734 | 8400 | 556 |
| 23 | 11080 | 791 | 11370 | 729 | 9920 | 766 | 8690 | 567 |
| 24 | 11420 | 803 | 11770 | 634 | 10110 | 743 | 9040 | 620 |
| 25 | 11860 | 863 | 12130 | 750 | 10490 | 759 | 9320 | 662 |
| 26 | 12390 | 931 | 12700 | 780 | 10940 | 715 | 9760 | 655 |
| 27 | 13090 | 955 | 13030 | 872 | 11280 | 751 | 10160 | 694 |
| 28 | 13760 | 1031 | 13630 | 813 | 11700 | 787 | 10560 | 703 |
| 29 | 14100 | 1007 | 13810 | 803 | 12250 | 879 | 10900 | 710 |
| 30 | 14530 | 952 | 14390 | 873 | 12630 | 832 | 11120 | 740 |
| 31 | 15160 | 1029 | 14850 | 1003 | 13010 | 909 | 11630 | 822 |
| 32 | 15650 | 1027 | 15300 | 956 | 13540 | 887 | 11950 | 836 |
| 33 | 16620 | 1136 | 15750 | 1039 | 13920 | 937 | 12560 | 857 |
| 34 | 17150 | 859 | 16920 | 1049 | 14450 | 874 | 13070 | 870 |
| 35 | 17740 | 1108 | 17480 | 1155 | 14760 | 961 | 13510 | 828 |
| 36 | 18260 | 1082 | 18680 | 1022 | 15220 | 1035 | 13810 | 924 |
| 37 | 19070 | | 19210 | 1268 | 15800 | 1124 | 14450 | 1011 |
| 38 | | | 20050 | | 17150 | 1129 | 15160 | 1059 |
| 39 | | | | | 17940 | 1190 | 15680 | 947 |
| 40 | | | | | 18970 | 1214 | 16460 | 932 |
| 41 | | | | | 19650 | 1371 | 16800 | 1049 |
| 42 | | | | | 20730 | | 18150 | 1178 |
| 43 | | | | | | | 19160 | 1165 |
| 44 | | | | | | | 20200 | |

| ROW | 20M LWT | 20FI H | 5M LWT | 5FI H | 23M LWT | 23FI H | 11M LWT | 11FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 8310 | 44 | 7600 | 80 | 7100 | 4 | 6940 | 42 |
| 2 | 8190 | 79 | 7510 | 69 | 6910 | 120 | 6590 | 68 |
| 3 | 8400 | 193 | 7540 | 173 | 7050 | 124 | 6890 | 234 |
| 4 | 8780 | 356 | 7930 | 196 | 7050 | 140 | 7450 | 264 |
| 5 | 9470 | 467 | 8380 | 261 | 6920 | 190 | 7800 | 341 |
| 6 | 10170 | 440 | 8700 | 211 | 6720 | 158 | 8040 | 320 |
| 7 | 10650 | 502 | 8900 | 327 | 6770 | 300 | 8270 | 304 |
| 8 | 10850 | 549 | 9210 | 266 | 6870 | 363 | 8590 | 327 |
| 9 | 11500 | 581 | 9690 | 310 | 7250 | 425 | 8980 | 274 |
| 10 | 11990 | 718 | 10050 | 403 | 7830 | 348 | 9420 | 361 |
| 11 | 12710 | 822 | 10570 | 472 | 8110 | 259 | 9820 | 336 |
| 12 | 13240 | 848 | 11100 | 526 | 8190 | 375 | 9920 | 465 |
| 13 | 14290 | 894 | 11600 | 680 | 8790 | 403 | 10280 | 501 |
| 14 | 15090 | 630 | 12320 | 592 | 9060 | 303 | 10870 | 656 |
| 15 | 15540 | 525 | 12770 | 774 | 9400 | 550 | 11710 | 567 |
| 16 | 15800 | 932 | 13550 | 871 | 10050 | 685 | 12030 | 568 |
| 17 | 16840 | 1088 | 14410 | 904 | 10620 | 621 | 12520 | 643 |
| 18 | 17570 | 1047 | 14740 | 849 | 11140 | 744 | 12760 | 620 |
| 19 | 18540 | 1101 | 15640 | 1026 | 11970 | 726 | 13360 | 645 |
| 20 | 18910 | | 16180 | 685 | 12300 | 630 | 13830 | 638 |
| 21 | | | 16810 | 1030 | 13040 | 811 | 14290 | 749 |
| 22 | | | 16900 | 877 | 13480 | 943 | 15020 | 707 |
| 23 | | | 18150 | 1171 | 14040 | 1014 | 15370 | 674 |
| 24 | | | 18670 | | 15410 | 1010 | 15790 | 920 |
| 25 | | | | | 16190 | 1285 | 16620 | 621 |
| 26 | | | | | 17430 | 782 | 16940 | 1154 |
| 27 | | | | | 17530 | 709 | 17920 | 744 |
| 28 | | | | | 17590 | 781 | 18370 | 1350 |
| 29 | | | | | 18290 | 1040 | 19230 | |
| 30 | | | | | 19150 | | | |

| ROW | 8M LWT | 8FI H | 2M LWT | 2FI H | 25M LWT | 25FI H | 32M LWT | 32FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 6130 | 44 | 5950 | 5 | 5180 | 46 | 7070 | 16 |
| 2 | 6000 | 115 | 5720 | 128 | 5110 | 194 | 6770 | 86 |
| 3 | 6360 | 268 | 6170 | 199 | 5610 | 268 | 6810 | 195 |
| 4 | 6930 | 345 | 6630 | 165 | 6290 | 250 | 7240 | 119 |
| 5 | 7690 | 402 | 6730 | 146 | 6350 | 293 | 7270 | 68 |
| 6 | 8200 | 444 | 6990 | 176 | 6620 | 235 | 7140 | 103 |
| 7 | 8770 | 512 | 7140 | 251 | 6940 | 325 | 7030 | 156 |
| 8 | 9490 | 330 | 7320 | 256 | 7260 | 461 | 7330 | 206 |
| 9 | 9260 | 407 | 7460 | 274 | 7820 | 337 | 7780 | 168 |
| 10 | 9540 | 570 | 7850 | 394 | 8090 | 344 | 7750 | 300 |
| 11 | 10100 | 551 | 8450 | 501 | 8440 | 429 | 8000 | 432 |
| 12 | 10820 | 656 | 9130 | 531 | 9030 | 475 | 8740 | 554 |
| 13 | 11450 | 633 | 9670 | 701 | 9550 | 438 | 9680 | 663 |
| 14 | 12250 | 661 | 10220 | 639 | 9660 | 577 | 10430 | 715 |
| 15 | 12650 | 800 | 10930 | 740 | 10320 | 693 | 11120 | 738 |
| 16 | 13600 | 905 | 11610 | 790 | 11100 | 690 | 11530 | 580 |
| 17 | 14520 | 682 | 12350 | 858 | 11690 | 618 | 11600 | 780 |
| 18 | 14780 | 635 | 12860 | 796 | 12200 | 700 | 12400 | 869 |
| 19 | 15860 | 852 | 13650 | 871 | 12760 | 605 | 13430 | 944 |
| 20 | 16660 | 713 | 14280 | 906 | 13230 | 696 | 13960 | 963 |
| 21 | 16980 | 1021 | 15170 | 975 | 13790 | 725 | 14810 | 1002 |
| 22 | 17960 | 861 | 15990 | 1052 | 14010 | 677 | 15580 | 1000 |
| 23 | 18790 | 961 | 16970 | 775 | 14460 | 818 | 16340 | 897 |
| 24 | 18950 | | 17530 | 997 | 15080 | 866 | 17020 | 1035 |
| 25 | | | 17850 | 731 | 15750 | 696 | 17430 | 790 |
| 26 | | | 18460 | 986 | 15990 | 664 | 17910 | |
| 27 | | | 18970 | | 16100 | 914 | | |
| 28 | | | | | 16860 | 1039 | | |
| 29 | | | | | 17760 | 1034 | | |
| 30 | | | | | 18410 | | | |

| ROW | 16M LWT | 16FI H | 35M LWT | 35FI H | 9F LWT | 9FI H | 4F LWT | 4FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 5810 | 17 | 8040 | 29 | 7910 | 57 | 7870 | 41 |
| 2 | 5640 | 200 | 7560 | 56 | 7810 | 200 | 7810 | 147 |
| 3 | 6160 | 289 | 7420 | 200 | 8150 | 386 | 8270 | 139 |
| 4 | 6550 | 168 | 8140 | 294 | 8750 | 617 | 8220 | 231 |
| 5 | 6500 | 115 | 8750 | 223 | 9600 | 341 | 8470 | 414 |
| 6 | 6360 | 123 | 8520 | 198 | 9730 | 302 | 9320 | 369 |
| 7 | 6350 | 164 | 8820 | 300 | 10060 | 296 | 9560 | 341 |
| 8 | 6590 | 307 | 9240 | 412 | 10330 | 425 | 9940 | 462 |
| 9 | 7120 | 464 | 9520 | 492 | 10660 | 508 | 10260 | 426 |
| 10 | 7670 | 401 | 10230 | 452 | 11370 | 553 | 10950 | 325 |
| 11 | 8060 | 404 | 10950 | 509 | 11830 | 646 | 11360 | 495 |
| 12 | 8380 | 296 | 11360 | 557 | 12410 | 553 | 11950 | 527 |
| 13 | 8570 | 372 | 11970 | 605 | 12600 | 710 | 12490 | 644 |
| 14 | 8780 | 391 | 12580 | 768 | 13200 | 756 | 13150 | 698 |
| 15 | 9180 | 435 | 12860 | 752 | 13570 | 844 | 13890 | 771 |
| 16 | 9720 | 476 | 13990 | 766 | 14330 | 933 | 14710 | 876 |
| 17 | 10020 | 581 | 14730 | 834 | 15110 | 1050 | 15250 | 955 |
| 18 | 10690 | 590 | 15430 | 847 | 15870 | 1038 | 16050 | 1148 |
| 19 | 11330 | 547 | 16200 | 1042 | 16290 | 862 | 16880 | 850 |
| 20 | 11900 | 494 | 16800 | 919 | 17000 | 949 | 17410 | 1049 |
| 21 | 12230 | 600 | 17710 | 1197 | 17410 | 727 | 18050 | 819 |
| 22 | 12940 | 633 | 18380 | 954 | 17680 | 1211 | 18660 | 1288 |
| 23 | 13500 | 767 | 19300 | 1243 | 18750 |  | 19430 |  |
| 24 | 14150 | 614 | 19760 |  |  |  |  |  |
| 25 | 14840 | 693 |  |  |  |  |  |  |
| 26 | 15460 | 805 |  |  |  |  |  |  |
| 27 | 15950 | 891 |  |  |  |  |  |  |
| 28 | 16790 | 703 |  |  |  |  |  |  |
| 29 | 17470 | 1002 |  |  |  |  |  |  |
| 30 | 17930 | 781 |  |  |  |  |  |  |
| 31 | 18700 | 1055 |  |  |  |  |  |  |
| 32 | 19170 |  |  |  |  |  |  |  |

| ROW | 15F LWT | 15FI H | 26F LWT | 26FI H | 17F LWT | 17FI H | 10F LWT | 10FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 7780 | 42 | 7140 | 100 | 6480 | 42 | 6220 | 58 |
| 2 | 7600 | 156 | 6860 | 300 | 6320 | 148 | 6200 | 178 |
| 3 | 7870 | 331 | 7380 | 431 | 6620 | 234 | 6540 | 268 |
| 4 | 8530 | 190 | 8140 | 410 | 6860 | 206 | 7160 | 370 |
| 5 | 8600 | 210 | 8510 | 583 | 7060 | 172 | 7570 | 383 |
| 6 | 8740 | 205 | 9220 | 679 | 7110 | 160 | 7950 | 314 |
| 7 | 9200 | 363 | 10150 | 645 | 7210 | 195 | 8280 | 381 |
| 8 | 9470 | 486 | 10650 | 667 | 7450 | 226 | 8720 | 408 |
| 9 | 10260 | 583 | 11100 | 662 | 7560 | 200 | 9200 | 507 |
| 10 | 10720 | 534 | 11640 | 616 | 7570 | 294 | 9820 | 427 |
| 11 | 11210 | 495 | 12230 | 774 | 7970 | 268 | 9600 | 286 |
| 12 | 11610 | 545 | 12740 | 602 | 8340 | 304 | 9650 | 477 |
| 13 | 12200 | 543 | 13320 | 620 | 8550 | 422 | 10080 | 619 |
| 14 | 12760 | 686 | 13860 | 663 | 9010 | 550 | 10960 | 752 |
| 15 | 13430 | 811 | 14160 | 844 | 9370 | 351 | 11580 | 830 |
| 16 | 14340 | 865 | 15200 | 981 | 9640 | 592 | 12300 | 860 |
| 17 | 15170 | 909 | 15800 | 1170 | 10180 | 549 | 12800 | 894 |
| 18 | 16000 | 857 | 16650 | 839 | 10540 | 616 | 13590 | 685 |
| 19 | 16380 | 657 | 17620 | 1203 | 11300 | 538 | 13890 | 821 |
| 20 | 17030 | 811 | 18060 | 1002 | 11900 | 598 | 14640 | 870 |
| 21 | 17350 | 762 | 19040 | 1253 | 12550 | 733 | 15290 | 988 |
| 22 | 17990 | 744 | 19540 | | 13050 | 696 | 15890 | 1161 |
| 23 | 18190 | | | | 13770 | 779 | 17150 | 896 |
| 24 | | | | | 14490 | 911 | 17530 | 1193 |
| 25 | | | | | 15300 | 796 | 18380 | 769 |
| 26 | | | | | 15960 | 1077 | 18490 | |
| 27 | | | | | 16860 | 752 | | |
| 28 | | | | | 17310 | 1143 | | |
| 29 | | | | | 17950 | 956 | | |
| 30 | | | | | 18770 | 1202 | | |
| 31 | | | | | 19550 | | | |

| ROW | 38F LWT | 38FI H | 33F LWT | 33FI H | 37F LWT | 37FI H | 31F LWT | 31FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 6670 | 8 | 7810 | 12 | 5920 | 16 | 4590 | 16 |
| 2 | 6290 | 77 | 7420 | 92 | 5480 | 42 | 4220 | 68 |
| 3 | 6260 | 200 | 7840 | 225 | 5450 | 200 | 4300 | 217 |
| 4 | 6980 | 296 | 7940 | 101 | 6110 | 300 | 4750 | 222 |
| 5 | 7330 | 337 | 7800 | 44 | 6780 | 314 | 5290 | 222 |
| 6 | 7640 | 326 | 7370 | 12 | 6920 | 296 | 5650 | 254 |
| 7 | 7900 | 366 | 7070 | 76 | 7220 | 297 | 5900 | 250 |
| 8 | 8540 | 276 | 7360 | 183 | 7510 | 355 | 6080 | 323 |
| 9 | 8790 | 364 | 7930 | 207 | 7820 | 391 | 6520 | 337 |
| 10 | 9020 | 339 | 7970 | 315 | 8100 | 431 | 6820 | 335 |
| 11 | 9360 | 494 | 8570 | 449 | 8520 | 591 | 7320 | 375 |
| 12 | 9860 | 518 | 9050 | 439 | 9220 | 699 | 7680 | 385 |
| 13 | 10360 | 502 | 9450 | 380 | 10000 | 597 | 7980 | 490 |
| 14 | 10810 | 646 | 9690 | 523 | 10440 | 749 | 8500 | 539 |
| 15 | 11480 | 426 | 10120 | 686 | 11050 | 700 | 9180 | 480 |
| 16 | 11700 | 521 | 11000 | 673 | 11660 | 819 | 9380 | 572 |
| 17 | 12340 | 742 | 11540 | 639 | 12320 | 871 | 9910 | 654 |
| 18 | 12940 | 773 | 12120 | 712 | 13210 | 850 | 10510 | 682 |
| 19 | 13720 | 1010 | 12820 | 745 | 13850 | 878 | 11210 | 780 |
| 20 | 15050 | 1052 | 13630 | 738 | 14670 | 981 | 11780 | 779 |
| 21 | 15890 | 916 | 14260 | 780 | 15340 | 1075 | 12640 | 779 |
| 22 | 16350 | 838 | 14840 | 753 | 16000 | 994 | 13170 | 839 |
| 23 | 17300 | 1135 | 15570 | 1004 | 16850 | 887 | 14310 | 884 |
| 24 | 17640 | 674 | 16520 | 770 | 17560 | 1002 | 14650 | 1004 |
| 25 | 17970 | 1199 | 17030 | 1029 | 18000 | 1021 | 15150 | 910 |
| 26 | 18760 | | 17760 | 760 | 18630 | 1215 | 15850 | 1060 |
| 27 | | | 18060 | 1107 | 19710 | | 16530 | 809 |
| 28 | | | 18960 | 802 | | | 17130 | 1161 |
| 29 | | | 19170 | | | | 17600 | 946 |
| 30 | | | | | | | 18260 | 1231 |
| 31 | | | | | | | 18930 | |

(ii) **Period B**

| ROW | 18M LWT | 18FI L | 3M LWT | 3FI L | 39F LWT | 39FI L | 40F LWT | 40FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 20410 | 1205 | 21020 | 1330 | 20050 | 932 | 19540 | 1034 |
| 2 | 21090 | 1160 | 21700 | 1399 | 20450 | 878 | 19840 | 1077 |
| 3 | 21940 | 1290 | 22580 | 1428 | 20570 | 952 | 20490 | 982 |
| 4 | 22480 | 1361 | 22850 | 1504 | 20980 | 1100 | 21040 | 981 |
| 5 | 22960 | 1436 | 23740 | 1378 | 21550 | 1080 | 21290 | 1118 |
| 6 | 23580 | 1389 | 24200 | 1443 | 22230 | 1170 | 21830 | 1112 |
| 7 | 24480 | 1377 | 24940 | 1469 | 22710 | 1226 | 22340 | 990 |
| 8 | 24880 | 1409 | 25740 | 1421 | 23320 | 1220 | 22840 | 1254 |
| 9 | 25970 | 1575 | 26220 | 1468 | 23720 | 1217 | 23460 | 1379 |
| 10 | 26700 | 1597 | 27060 | 1407 | 24280 | 1258 | 24460 | 1358 |
| 11 | 27140 | 1552 | 27450 | 1408 | 25000 | 1371 | 24760 | 1470 |
| 12 | 27890 | 1765 | 28090 | 1538 | 25720 | 1376 | 25700 | 1430 |
| 13 | 28810 | 1847 | 28810 | 1673 | 26080 | 1350 | 26340 | 1423 |
| 14 | 29420 | 1557 | 29480 | 1591 | 26920 | 1228 | 26950 | 1515 |
| 15 | 30430 | 1872 | 30620 | 1569 | 27340 | 1277 | 27600 | 1649 |
| 16 | 31170 | 1749 | 31000 | 1574 | 27840 | 1388 | 28380 | 1650 |
| 17 | 31450 | 1855 | 32360 | 1255 | 28510 | 1341 | 29440 | 1724 |
| 18 | 32620 | | 33120 | | 29310 | 1546 | 30090 | 1638 |
| 19 | | | | | 29940 | 1263 | 31030 | 1560 |
| 20 | | | | | 30410 | 1368 | 31370 | 1571 |
| 21 | | | | | 31020 | 1404 | 32480 | 1530 |
| 22 | | | | | 31690 | 1482 | 33080 | |
| 23 | | | | | 32340 | | | |

| ROW | 22M LWT | 22FI H | 12M LWT | 12FI H | 24F LWT | 24FI H | 34F LWT | 34FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 20900 | 1177 | 19910 | 1000 | 20730 | 1456 | 20310 | 1249 |
| 2 | 22400 | 1087 | 20980 | 1031 | 22090 | 1369 | 21410 | 1085 |
| 3 | 23020 | 1229 | 21420 | 1025 | 23010 | 1430 | 22250 | 1070 |
| 4 | 24480 | 1290 | 22020 | 947 | 24400 | 1552 | 23080 | 1170 |
| 5 | 25770 | 1376 | 22950 | 1023 | 25820 | 1531 | 24090 | 1260 |
| 6 | 26790 | 1251 | 23780 | 1094 | 27020 | 1513 | 24940 | 1303 |
| 7 | 27700 | 1302 | 24530 | 1124 | 28020 | 1580 | 25900 | 1257 |
| 8 | 28720 | 1365 | 25200 | 1110 | 28920 | 1644 | 27080 | 1194 |
| 9 | 29520 | 1356 | 25960 | 1092 | 29950 | 1759 | 27850 | 1347 |
| 10 | 30160 | 1412 | 26990 | 1007 | 31400 | 1793 | 28450 | 1316 |
| 11 | 31350 | 1500 | 27330 | 1197 | 32550 | | 29290 | 1323 |
| 12 | 32140 | 1454 | 28280 | 1221 | | | 30300 | 1406 |
| 13 | 32940 | | 28920 | 1282 | | | 31280 | 1292 |
| 14 | | | 29800 | 1379 | | | 32030 | 1381 |
| 15 | | | 30630 | 1395 | | | 32710 | |
| 16 | | | 31330 | 1510 | | | | |
| 17 | | | 32430 | 1524 | | | | |
| 18 | | | 32930 | | | | | |

| ROW | 21M LWT | 21FI H | 21FI L | 28M LWT | 28FI H | 28FI L | 30F LWT | 30FI H | 30FI L |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 21360 | 1378 | 0 | 20340 | 1134 | 37 | 19460 | 393 | 878 |
| 2 | 22260 | 1398 | 0 | 21360 | 1251 | 13 | 20640 | 487 | 724 |
| 3 | 23680 | 1450 | 1 | 22430 | 1325 | 5 | 21520 | 490 | 648 |
| 4 | 24840 | 1235 | 0 | 23700 | 1099 | 186 | 22060 | 530 | 690 |
| 5 | 25990 | 1006 | 2 | 24770 | 1140 | 198 | 22860 | 640 | 804 |
| 6 | 27110 | 1219 | 2 | 25700 | 1216 | 73 | 23660 | 666 | 769 |
| 7 | 28130 | 1142 | 3 | 26960 | 978 | 367 | 24780 | 628 | 734 |
| 8 | 28900 | 1233 | 0 | 27720 | 975 | 261 | 25400 | 803 | 852 |
| 9 | 29860 | 1248 | 49 | 28570 | 916 | 460 | 26730 | 479 | 803 |
| 10 | 30470 | 1367 | 61 | 29210 | 931 | 474 | 27480 | 509 | 923 |
| 11 | 31740 | 1275 | 84 | 30520 | 690 | 643 | 28180 | 346 | 1103 |
| 12 | 32360 | | | 31250 | 709 | 701 | 29080 | 443 | 1089 |
| 13 | | | | 32390 | 930 | 715 | 30040 | 395 | 1093 |
| 14 | | | | 33510 | | | 31020 | 411 | 1235 |
| 15 | | | | | | | 31650 | 265 | 1289 |
| 16 | | | | | | | 32350 | 561 | 1286 |
| 17 | | | | | | | 33450 | | |

| ROW | 29F LWT | 29FI H | 29FI L | 13F LWT | 13FI H | 13FI L | 1F LWT | 1FI H | 1FI L |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 19070 | 334 | 758 | 20490 | 1410 | 418 | 19560 | 624 | 931 |
| 2 | 19940 | 456 | 820 | 22500 | 1522 | 131 | 20810 | 612 | 560 |
| 3 | 21130 | 381 | 851 | 24140 | 1588 | 0 | 21350 | 235 | 521 |
| 4 | 21540 | 558 | 859 | 24710 | 1424 | 191 | 22060 | 498 | 410 |
| 5 | 22840 | 402 | 937 | 25740 | 1390 | 376 | 22310 | 596 | 540 |
| 6 | 23710 | 414 | 854 | 27410 | 1389 | 450 | 22950 | 202 | 852 |
| 7 | 24310 | 519 | 1015 | 28980 | 1380 | 523 | 23570 | 281 | 891 |
| 8 | 25400 | 535 | 1188 | 29890 | 1115 | 753 | 24050 | 236 | 706 |
| 9 | 26690 | 611 | 1191 | 31270 | 1302 | 590 | 24520 | 375 | 702 |
| 10 | 27890 | 508 | 1309 | 32360 | 945 | 426 | 24770 | 214 | 1001 |
| 11 | 29590 | 514 | 1364 | 33450 | 970 | 359 | 25500 | 391 | 649 |
| 12 | 30170 | 452 | 1394 | 33540 | | | 26210 | 315 | 679 |
| 13 | 31420 | 520 | 1471 | | | | 26270 | 275 | 764 |
| 14 | 32670 | | | | | | 26830 | 263 | 841 |
| 15 | | | | | | | 27430 | 298 | 810 |
| 16 | | | | | | | 28500 | 419 | 589 |
| 17 | | | | | | | 28820 | 314 | 958 |
| 18 | | | | | | | 29540 | 272 | 742 |
| 19 | | | | | | | 30100 | 373 | 804 |
| 20 | | | | | | | 31000 | 373 | 881 |
| 21 | | | | | | | 31600 | 383 | 1081 |
| 22 | | | | | | | 32680 | | |

| ROW | 6M LWT | 6FI H | 6FI L | 14M LWT | 14FI H | 14FI L | 25M LWT | 25FI L |
|---|---|---|---|---|---|---|---|---|
| 1 | 20480 | 1210 | 0 | 20910 | 1190 | 29 | 18410 | 1165 |
| 2 | 21740 | 1132 | 4 | 21780 | 1082 | 118 | 19040 | 1170 |
| 3 | 22430 | 1043 | 45 | 22870 | 1125 | 40 | 19640 | 1187 |
| 4 | 23540 | 1137 | 26 | 23790 | 1009 | 100 | 20260 | 1284 |
| 5 | 24630 | 1130 | 45 | 24970 | 907 | 340 | 20760 | 1174 |
| 6 | 25790 | 1166 | 51 | 25790 | 807 | 277 | 21100 | 1378 |
| 7 | 26530 | 1064 | 86 | 26810 | 1168 | 13 | 21540 | 1488 |
| 8 | 27540 | 1094 | 182 | 27640 | 1070 | 175 | 22000 | 1679 |
| 9 | 28900 | 1065 | 86 | 28800 | 1173 | 9 | 23520 | 1719 |
| 10 | 29840 | 1127 | 227 | 29600 | 1345 | 10 | 24020 | 1285 |
| 11 | 30890 | 1119 | 220 | 30830 | 1420 | 4 | 24750 | 1396 |
| 12 | 32250 | 1060 | 182 | 31930 | 1023 | 308 | 25290 | 1535 |
| 13 | 32600 | | | 32940 | 1100 | 397 | 26360 | 1606 |
| 14 | | | | 34000 | | | 26680 | 1568 |
| 15 | | | | | | | 27510 | 1335 |
| 16 | | | | | | | 28280 | 1698 |
| 17 | | | | | | | 28710 | 1729 |
| 18 | | | | | | | 29870 | 1867 |
| 19 | | | | | | | 30550 | 1842 |
| 20 | | | | | | | 31560 | 1867 |
| 21 | | | | | | | 32250 | 1527 |
| 22 | | | | | | | 32940 | |

| ROW | 11M LWT | 11FI L | 17F LWT | 17FI L | 4F LWT | 4FI L | 35M LWT | 35FI H |
|---|---|---|---|---|---|---|---|---|
| 1 | 19230 | 1037 | 19550 | 1244 | 19430 | 1109 | 19760 | 887 |
| 2 | 19620 | 1080 | 20330 | 1284 | 19910 | 1104 | 20190 | 1112 |
| 3 | 19920 | 1143 | 20870 | 1331 | 20370 | 1209 | 21300 | 1191 |
| 4 | 20300 | 1207 | 21170 | 1194 | 20740 | 1259 | 22030 | 1249 |
| 5 | 20890 | 1291 | 22130 | 1199 | 21480 | 1304 | 23000 | 1316 |
| 6 | 21600 | 1309 | 22410 | 1344 | 22070 | 1329 | 24030 | 1387 |
| 7 | 22170 | 1392 | 23280 | 1394 | 22840 | 1359 | 24930 | 1476 |
| 8 | 23090 | 1448 | 24130 | 1500 | 23670 | 1452 | 25890 | 1590 |
| 9 | 23750 | 1443 | 24810 | 1225 | 24300 | 1514 | 27040 | 1655 |
| 10 | 24300 | 1292 | 24950 | 1472 | 25110 | 1579 | 28270 | 1383 |
| 11 | 24850 | 1455 | 25850 | 1420 | 25730 | 1533 | 29100 | 1434 |
| 12 | 25510 | 1430 | 26700 | 1438 | 26720 | 1570 | 29650 | 1496 |
| 13 | 26350 | 1508 | 27350 | 1428 | 27560 | 1591 | 30360 | 1358 |
| 14 | 26920 | 1647 | 27670 | 1514 | 28410 | 1619 | 30750 | 1489 |
| 15 | 27760 | 1800 | 28740 | 1616 | 29290 | 1679 | 32100 | 1543 |
| 16 | 28880 | 1807 | 29380 | 1510 | 30050 | 1714 | 33460 | |
| 17 | 29800 | 1598 | 29790 | 1479 | 30570 | 1616 | | |
| 18 | 30400 | 1536 | 30640 | 1539 | 31430 | 1833 | | |
| 19 | 31120 | 1434 | 31510 | 1440 | 32010 | 1853 | | |
| 20 | 31640 | 1507 | 31950 | 1606 | 32530 | | | |
| 21 | 32340 | 1564 | 32640 | | | | | |
| 22 | 32900 | | | | | | | |

| ROW | 2M LWT | 2FI H | 15F LWT | 15FI H | 38F LWT | 38FI H | 5M LWT | 5FI H | 5FI L |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 18970 | 836 | 18190 | 726 | 18760 | 978 | 18670 | 104 | 919 |
| 2 | 19730 | 882 | 18650 | 977 | 19250 | 969 | 19500 | 348 | 847 |
| 3 | 20450 | 955 | 19530 | 990 | 19750 | 1098 | 19810 | 323 | 938 |
| 4 | 21030 | 980 | 20720 | 1066 | 20660 | 1151 | 20590 | 333 | 1011 |
| 5 | 21610 | 1075 | 21390 | 1155 | 21450 | 1158 | 21450 | 499 | 800 |
| 6 | 22370 | 1059 | 22310 | 1207 | 22330 | 1229 | 22370 | 304 | 956 |
| 7 | 23150 | 1095 | 23330 | 1240 | 23110 | 1224 | 23090 | 463 | 825 |
| 8 | 24090 | 1152 | 24260 | 1301 | 24350 | 1331 | 23970 | 259 | 984 |
| 9 | 24920 | 1174 | 24840 | 1322 | 25540 | 1394 | 24740 | 467 | 756 |
| 10 | 25750 | 1130 | 26370 | 1358 | 26530 | 1421 | 25600 | 220 | 948 |
| 11 | 26430 | 1030 | 26950 | 1331 | 27310 | 1360 | 26220 | 205 | 1154 |
| 12 | 27080 | 1082 | 28150 | 1256 | 28110 | 1307 | 26920 | 223 | 1099 |
| 13 | 27900 | 1171 | 28850 | 1295 | 28970 | 1450 | 27440 | 340 | 1046 |
| 14 | 28490 | 1180 | 29330 | 1326 | 30170 | 1403 | 28610 | 217 | 1092 |
| 15 | 29290 | 1177 | 30320 | 1311 | 30990 | 1527 | 29250 | 472 | 1099 |
| 16 | 29980 | 1416 | 31140 | 1403 | 31960 | 1632 | 30300 | 257 | 1272 |
| 17 | 31020 | 1339 | 32290 | 1405 | 32710 |  | 30930 | 295 | 915 |
| 18 | 31430 | 1315 | 32610 |  |  |  | 31340 | 451 | 1147 |
| 19 | 32320 | 1439 |  |  |  |  | 32180 | 474 | 943 |
| 20 | 32820 |  |  |  |  |  | 33130 |  |  |

| ROW | 16M LWT | 16FI H | 16FI L | 23M LWT | 23FI H | 23FI L | 8M LWT | 8FI H | 8FI L |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 19170 | 423 | 542 | 19150 | 430 | 589 | 18950 | 691 | 575 |
| 2 | 19720 | 496 | 458 | 19790 | 571 | 547 | 20250 | 646 | 426 |
| 3 | 20430 | 432 | 623 | 20550 | 632 | 500 | 21060 | 669 | 370 |
| 4 | 20940 | 510 | 395 | 21420 | 746 | 424 | 21960 | 675 | 384 |
| 5 | 21820 | 341 | 637 | 22350 | 616 | 449 | 22440 | 708 | 466 |
| 6 | 22310 | 442 | 598 | 22870 | 560 | 586 | 23080 | 816 | 471 |
| 7 | 22840 | 257 | 819 | 23730 | 536 | 584 | 23940 | 669 | 417 |
| 8 | 23660 | 539 | 672 | 24410 | 426 | 854 | 24770 | 598 | 371 |
| 9 | 24290 | 462 | 709 | 25330 | 545 | 924 | 25470 | 708 | 397 |
| 10 | 25020 | 488 | 709 | 26360 | 325 | 937 | 25930 | 703 | 532 |
| 11 | 25880 | 416 | 790 | 27670 | 472 | 977 | 27100 | 779 | 392 |
| 12 | 26890 | 324 | 849 | 28340 | 533 | 977 | 27920 | 814 | 666 |
| 13 | 27610 | 222 | 968 | 29280 | 637 | 715 | 28790 | 819 | 654 |
| 14 | 28310 | 510 | 780 | 30030 | 464 | 932 | 30090 | 832 | 578 |
| 15 | 29360 | 179 | 1033 | 30920 | 411 | 969 | 31080 | 861 | 614 |
| 16 | 29720 | 565 | 830 | 31600 | 352 | 1115 | 31990 | 883 | 545 |
| 17 | 30670 | 463 | 899 | 32670 | 508 | 1175 | 32700 |  |  |
| 18 | 31710 | 489 | 969 | 33590 |  |  |  |  |  |
| 19 | 32790 |  |  |  |  |  |  |  |  |

| ROW | 9F LWT | 9FI H | 9FI L | 26F LWT | 26FI H | 26FI L | 37F LWT | 37FI H | 37FI L |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 18750 | 135 | 1007 | 19540 | 288 | 999 | 19710 | 46 | 1111 |
| 2 | 19480 | 178 | 1067 | 20560 | 292 | 1083 | 20230 | 6 | 1157 |
| 3 | 20190 | 174 | 1037 | 21190 | 348 | 859 | 20630 | 13 | 1218 |
| 4 | 20800 | 107 | 1126 | 21790 | 250 | 1087 | 21380 | 0 | 1156 |
| 5 | 21600 | 94 | 1181 | 22850 | 398 | 980 | 21950 | 25 | 1065 |
| 6 | 22090 | 25 | 1128 | 23380 | 383 | 868 | 22060 | 389 | 681 |
| 7 | 22540 | 75 | 1123 | 23980 | 409 | 1004 | 23250 | 244 | 1201 |
| 8 | 23330 | 175 | 1092 | 25150 | 496 | 942 | 24350 | 218 | 1242 |
| 9 | 23760 | 145 | 1242 | 25750 | 383 | 1125 | 25110 | 215 | 1138 |
| 10 | 24590 | 238 | 1226 | 26770 | 299 | 1155 | 25750 | 185 | 1280 |
| 11 | 25350 | 154 | 1231 | 27580 | 394 | 1107 | 26800 | 455 | 1073 |
| 12 | 26080 | 140 | 1113 | 28900 | 431 | 986 | 27790 | 308 | 1070 |
| 13 | 26670 | 260 | 1144 | 29630 | 262 | 1095 | 28490 | 512 | 1108 |
| 14 | 27380 | 240 | 1208 | 29950 | 250 | 1121 | 29780 | 308 | 1040 |
| 15 | 28250 | 370 | 1243 | 30650 | 165 | 1192 | 30100 | 390 | 1262 |
| 16 | 29040 | 231 | 1309 | 31440 | 133 | 969 | 31260 | 333 | 1295 |
| 17 | 29670 | 208 | 1335 | 31970 | 294 | 971 | 32270 | 187 | 1332 |
| 18 | 30520 | 171 | 1388 | 32530 | 482 | 726 | 32750 | | |
| 19 | 31310 | 179 | 1444 | 32780 | | | | | |
| 20 | 32080 | 73 | 1388 | | | | | | |
| 21 | 32590 | | | | | | | | |

| ROW | 31F LWT | 31FI H | 31FI L |
|---|---|---|---|
| 1 | 18930 | 16 | 1190 |
| 2 | 19720 | 134 | 1191 |
| 3 | 20260 | 116 | 1277 |
| 4 | 21020 | 187 | 1325 |
| 5 | 21840 | 238 | 1335 |
| 6 | 22950 | 202 | 1364 |
| 7 | 23750 | 145 | 1402 |
| 8 | 24760 | 193 | 1283 |
| 9 | 25260 | 397 | 1242 |
| 10 | 25980 | 314 | 1335 |
| 11 | 27080 | 162 | 1357 |
| 12 | 27720 | 343 | 1403 |
| 13 | 28880 | 253 | 1389 |
| 14 | 29630 | 341 | 1440 |
| 15 | 30270 | 376 | 1360 |
| 16 | 31210 | 317 | 1314 |
| 17 | 31970 | | |

## F. Chemical Data - Experiment 5

LWT = Liveweight at slaughter (g); EBWT = Empty Body Weight (g); WATER, PROT, LIPID and ASH = Water, Protein, Lipid and Ash in the empty body (g); GROSSEN = Gross Energy (kJ/g EBW); PIGNO = Pig Identity

### (i) Period A

Males No: 20, 32, 10, 33. Females No: 7, 19, 27, 36

| ROW | LWT | EBWT | WATER | PROT | LIPID | ASH | GROSSEN | PIGNO |
|---|---|---|---|---|---|---|---|---|
| 1 | 18910 | 17800 | 12264.2 | 2789.97 | 1871.14 | 559.098 | 7.93 | 20 |
| 2 | 17910 | 16700 | 11506.3 | 2633.26 | 1843.85 | 477.787 | 7.99 | 32 |
| 3 | 18490 | 17480 | 11921.4 | 2823.72 | 2006.70 | 466.891 | 8.33 | 10 |
| 4 | 19170 | 18080 | 12366.7 | 2942.34 | 1953.91 | 559.938 | 8.05 | 33 |
| 5 | 19180 | 17880 | 11586.2 | 2668.59 | 2901.39 | 478.290 | 9.84 | 7 |
| 6 | 19960 | 18860 | 12466.5 | 2870.68 | 2717.35 | 575.419 | 9.21 | 19 |
| 7 | 18300 | 17520 | 10879.9 | 2596.29 | 3253.64 | 551.179 | 10.70 | 27 |
| 8 | 20200 | 18840 | 12227.2 | 2777.39 | 3022.12 | 595.156 | 9.69 | 36 |

### (ii) Period B

Males No: 5, 16, 8, 23, 14, 6, 21, 28. Females No: 9, 26, 31, 37, 30,29, 13, 1.

| ROW | LWT | EBWT | WATER | PROT | LIPID | ASH | GROSSEN | PIGNO |
|---|---|---|---|---|---|---|---|---|
| 1 | 33130 | 31860 | 21378.1 | 5324.76 | 3710.73 | 1058.71 | 8.53 | 5 |
| 2 | 32790 | 31200 | 21153.6 | 5314.61 | 3295.34 | 1034.90 | 8.24 | 16 |
| 3 | 32700 | 31540 | 22141.1 | 5131.87 | 2979.58 | 911.82 | 7.57 | 8 |
| 4 | 33590 | 32940 | 21905.1 | 5318.82 | 4314.81 | 1026.41 | 8.86 | 23 |
| 5 | 32590 | 31000 | 19065.0 | 4845.61 | 5776.54 | 943.02 | 10.98 | 9 |
| 6 | 32780 | 31580 | 20305.9 | 5287.44 | 4611.00 | 1048.46 | 9.60 | 26 |
| 7 | 31970 | 30420 | 18404.1 | 4758.30 | 6140.28 | 829.25 | 11.43 | 31 |
| 8 | 32750 | 31220 | 19668.6 | 5741.05 | 4297.12 | 1166.69 | 9.79 | 37 |
| 9 | 34000 | 32780 | 21733.1 | 4794.40 | 4783.26 | 1082.72 | 8.95 | 14 |
| 10 | 32600 | 31300 | 20971.0 | 5360.75 | 3398.24 | 1146.52 | 8.44 | 6 |
| 11 | 32360 | 31280 | 21082.7 | 5057.98 | 3803.65 | 917.76 | 8.49 | 21 |
| 12 | 33510 | 32140 | 21983.8 | 5291.53 | 3290.49 | 1046.16 | 8.01 | 28 |
| 13 | 33450 | 31860 | 18829.3 | 5003.93 | 6671.80 | 938.28 | 11.87 | 30 |
| 14 | 32670 | 30760 | 18886.6 | 4654.30 | 5800.41 | 1021.23 | 10.86 | 29 |
| 15 | 33540 | 31980 | 20819.0 | 5011.27 | 4844.01 | 948.85 | 9.49 | 13 |
| 16 | 32680 | 31460 | 19914.2 | 5114.77 | 5114.77 | 923.67 | 10.13 | 1 |